PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE

ESCUELA DE INGENIERIA

DESIGN AND ASSESSMENT OF INCENTIVES TO THE INCORPORATION OF ENERGY EFFICIENCY MEASURES

SONIA E. VERA OÑAT

Thesis submitted to the Office of Research and Graduate Studies in partial fulfillment of the requirements for the Degree of Master of Science in Engineering (or Doctor in Engineering Sciences)

Advisor:

ENZO E. SAUMA SANTIS

Santiago de Chile, march, 2015

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To my family members and friends. Each of them is a wonderful gift from God.

“The Lamb who was killed is worthy to receive power, riches, wisdom, strength, honor, glory, and praise” (Rev.5.12)

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First I want to thank my family and friends for their unconditional help, support and encouragement. Especially I thank my husband, daughters, mother and grandson, for their love and foolproof patience. I also wish to thank my advisor Enzo Sauma, who from the first day encouraged me and guided me with a dedication that only great masters can provide. He has been a role model in many ways.

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Above all, I want to thank God because “Every good and perfect gift comes down from the Father who created all the lights in the heavens” (James1.17)

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ESCUELA DE INGENIERIA

DISEÑO Y EVALUACIÓN DE INCENTIVOS PARA LA INCORPORACIÓN DE MEDIDAS DE EFICIENCIA ENERGÉTICA

Tesis enviada a la Dirección de Investigación y Postgrado en cumplimiento parcial de los requisitos para el grado de Doctor en Ciencias de la Ingeniería.

SONIA EDITH VERA OÑAT

RESUMEN

En este trabajo se ha estudiado y evaluado el diseño de algunas medidas o mecanismos para mejorar el uso eficiente de la energía en Chile. Entendiendo la eficiencia energética (EE) como las acciones que optimizan la relación entre la cantidad de energía consumida y la cantidad final de productos y servicios obtenidos con ella, es pertinente preguntar ¿Por qué incentivar la EE en un país como Chile? La respuesta a esta pregunta tiene tres aristas fundamentales.

En primer lugar, para crecer de manera sustentable como país, es necesario contar con energía limpia al menor costo posible. Sin embargo, basta con observar la proyección de crecimiento de la demanda de energía eléctrica en el país para los próximos años, la composición de fuentes de energía primaria con las que se está generando electricidad hoy en día, y los precios a los que está disponible la energía, para darse cuenta que sí es necesario tomar una serie de medidas conducentes a hacer un uso más eficiente de la energía que consume el país.

Este desafío, sin embargo, no es solo de Chile. Son muchos los países que desde hace un tiempo están trabajando en incorporar medidas de EE en sus mercados de energía. Los mecanismos para promover la EE son muy variados, incluyen medidas como la entrega de información respecto a los consumos de los artefactos electrónicos domiciliarios, la incorporación de nuevas tecnologías de producción y transporte más eficientes y la

creación y fortalecimiento de una institucionalidad, pública o privada, encargada de la promoción, diseño, evaluación y seguimiento de las medidas implementadas.

A este respecto, es necesario señalar que para ser más efectiva la promoción de la EE, es necesario aplicar mecanismos diseñados e implementados considerando no sólo las características del instrumento en sí, sino también del público al cual están dirigidas. En esta línea, este trabajo ha contribuido con el diseño de una metodología para la evaluación de impactos, directos e indirectos, de los programas de EE, que permite además detectar factores que influyen en los resultados del programa. Esta metodología se aplicó en la evaluación de 12 programas de EE, implementados entre el año 2011 y 2012, por la Agencia Chilena de Eficiencia Energética (AChEE). La evaluación se centró en los impactos indirectos de dichos programas y el resultado general obtenido permite señalar que los participantes y beneficiarios de los programas de la AChEE valoran muy positivamente el concepto de EE y la intervención de la que fueron partícipes, la que además los motivó a tomar diversas acciones de EE, tanto en el hogar como en su trabajo. La debilidad detectada, sin embargo, es la información y capacitación en el tema.

Por otra parte, y como se señaló anteriormente, existen variadas formas de promover la EE. Algunos mecanismos son de aplicación global y otros de aplicación más específica. Este trabajo ha contribuido con el diseño y determinación de los potenciales beneficios de un mecanismo de aplicación específica, como un sistema de tarificación flexible tipo Time Of Use, simétrico, para el sector residencial del Sistema Interconectado Central (SIC). Este esquema de tarificación, por una parte, permite dar señales de precios a los clientes residenciales de modo que tomen sus decisiones de consumo de acuerdo al costo de generar la energía, promoviendo así la EE y la disminución de sus gastos en energía eléctrica; y por otra parte, permite a las empresas distribuidoras de electricidad obtener beneficios económicos con respecto al caso base, correspondiente a un esquema tarifario fijo y regulado, de US$811,7 millones para el periodo de estudio (2005-2007), considerando iniciativas que promuevan un ahorro de 5% en el consumo durante las horas de mayor demanda durante los meses de verano y de invierno.

Finalmente, este trabajo contribuye a la evaluación y comparación de la efectividad de una medida global propuesta por el Gobierno de Chile para reducir las emisiones de gases de efecto invernadero, consistente en un impuesto de US$5/Ton CO_2e, y algunas medidas de EE en el sector eléctrico SIC. El análisis y comparación de estas medidas se ha realizado entendiendo que los mecanismos de EE, además de buscar optimizar el uso de la energía consumida, también tienen como objetivo reducir las emisiones de CO_2. Los resultados obtenidos indican que el impuesto al carbón propuesto produce en promedio una reducción de 1% en las emisiones de CO_2 en el SIC durante el periodo 2014-2024. Sin embargo, también produce un incremento promedio de 3.4% en el costo marginal de generación de energía. Por otra parte, este trabajo también muestra que la introducción de algunas medidas de EE que reduzcan en 2% la proyección de la demanda residencial en el SIC puede alcanzar mayores reducciones en las emisiones de CO_2 y simultáneamente no incrementar el precio de la energía.

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Santiago, marzo, 2015

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ABSTRACT

This work has studied and evaluated the design of some measures to improve the efficient use of energy in Chile. Understanding the energy efficiency (EE) as a set of actions that optimizes the relationship between the amount of energy consumed and the quantity of final products and services obtained, it is pertinent to ask: Why is it convenient to encourage EE in a country like Chile? The answer to this fundamental question has three edges.

First, to grow in a sustainable way as a country, it is necessary to have clean energy at the lowest possible cost. However, simply observing the growth forecast of electricity demand in the country for the coming years, the composition of primary energy sources to generate electricity today, and the prices at which is available this energy, is enough to realize that there is still space for improving the efficiency in the use of the energy consumed by Chile.

Nevertheless, this challenge is not faced only by Chile. Many countries have been working to incorporate EE measures in their energy markets. There are multiple mechanisms aiming this goal. For instance, they include measures such as: the provision of information regarding consumption of electronic appliances, new technologies to obtain more efficient production and transportation, the creation and strengthening of institutions (public or private) responsible for the development, design, evaluation and

monitoring of the implemented EE measures. Regarding this, it should be noted that, to be more effective in the promotion of the EE, it is necessary to work with mechanisms designed and implemented considering not only the characteristics of the instrument itself, but also of the public to which they are directed. In this line, this work has contributed with the design of a methodology to assess the impacts of EE programs. Intending to evaluate both their direct and indirect impacts, and also detect key factors influencing program outcomes. This methodology was applied in the evaluation of 12 EE programs, implemented between 2011 and 2012 by the Chilean Energy Efficiency Agency (AChEE, for its acronym in Spanish). The evaluation focused on the indirect impacts of these programs and the overall result allowing perceiving that participants and beneficiaries of programs of the AChEE have a high valuation of the EE concept motivating them to take various EE actions, both at home and at work. The weakness detected, however, is the lack of information and the insufficient training on the subject.

Moreover, and as noted above, there are various ways to promote EE. Some mechanisms are of global applicability while others are more specific. This work has contributed to the design and estimation of a specific mechanism application and its potential benefits, such as a flexible pricing system of the Time Of Use (TOU) type. This mechanism is symmetric and it is applied in the residential sector of the Interconnected Central System (SIC). This pricing scheme, first, allows us to give price signals to residential customers so that they make their consumption decisions according to the cost of energy, promoting EE and decreasing their expenses on electrical energy. Secondly, it enables distribution companies (DISCOs) to obtain economic benefits in relation to the base case, corresponding to a fixed and regulated tariff scheme. The benefits reached $ 811.7 million for the study period (2005-2007), considering initiatives that promote savings of 5% consumption during peak hours in summer and winter.

Finally, this work contributes to evaluate the effectiveness of a global measure, proposed by the Government of Chile to reduce emissions of greenhouse gases (consisting of a carbon tax of $ 5/tons CO_2e) compared to some EE measures in the electrical sector SIC. The analysis and comparison of these two measures was performed assuming that

energy efficiency mechanisms not only seek to optimize the use of energy consumed, but also aim to reduce CO_2 emissions. The results obtained indicate that the proposed carbon tax produces, in average, a reduction of 1% in the CO_2 emissions during the 2014-2024 period. However, an average increase of 3.4% in the marginal cost of power production is reached in the main Chilean power system by the carbon tax. On the contrary, this work shows that the introduction of some energy efficiency measures reducing 2% of power demand in the residential sector could achieve larger reductions in CO_2 emissions, while simultaneously not increasing the price of energy.

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Santiago, march, 2015

1. INTRODUCTION

The economic growth of developing countries like Chile, is associated with their ability to use energy in its multiple forms. Among the authors who have studied the relationship between the use of electrical power and GDP, it can be mentioned Asafu-Adjaye; Bozoklu and Yilanci; Cowan et al.; Fatai et al; Garg et al.; Hanson and Laitner; Javid and Qayyum; Lee; Morimoto and Hope; Ohler and Fetters; Vera et al.; Yıldırım et al. [1-13].

However, despite the benefits energy availability brings to the economies. Energy generation and use, entail some negative externalities especially in countries where energy production relies mainly on fossil fuels. This leads to greenhouse gas emissions causing climate change and global warming [3,5,14,15,16,17,18]. This situation, in general, has highlighted the need for countries to move towards sustainable economic growth and thus, to propose and establish measures to decrease their carbon emissions [19-23].

There is not a single solution to face this challenge; so different measures have been conduced worldwide attempting to solve this problem.

In this line, nowadays it can be observed in several countries, an increase of renewable energy to produce electricity [6,24]. These sources, also named non-emitting energy forms [25], include: eolian, solar, geothermal, hydro, and bioenergy, among others. The main objectives of these clean sources are decreasing reliance on imported energy, decoupling rising fossil energy use from economic growth and reducing CO_2 emissions [15,26-28]. Despite this fact, it can be seen the use of fossil fuels continues to grow [19].

In Chile, the sustained growth in the electricity consumption, which by 2010 reached approximately 58,000 GWh, 62% based on fossil fuels- coal, natural gas and oil-, and 35% based on hydro generation, and originated 63% in the industrial sector (including mining) and 32% in the commercial sector (including residential sector), has followed the growing trend of GDP [29]. However in the case of electricity demand, it has presented a higher rate of growth. As a result, the electric consumption has doubled every 10 years since 1987 [30] (See Figure III-1).

Moreover, considering the growth rates of the last years, approximately 6% to 7% per year, the government has estimated that the electricity consumption in Chile will reach almost 100,000 GWh by the year 2020 [31] (See Figure III-2).

The Chilean electric system is composed of 4 subsystems. The two largest systems are the Central Interconnected System (SIC) and the Northern Interconnected System (SING), which covered 99.5% of the total country electric generation in 2013. The SIC is the main system of the country. In 2013, the SIC reached 74.3% of the total country electric generation, while the SING reached 25.2% [32].

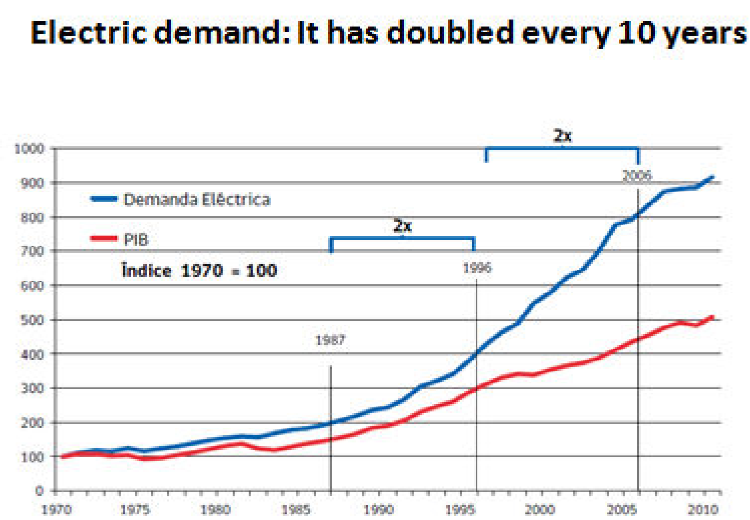

Figure III-1: Temporal evolution of the electric demand of Chile[1]

[1] Source: AIE & Chilean Ministry of Energy. Background on Chile's energy matrix and its challenges for the future. 2011

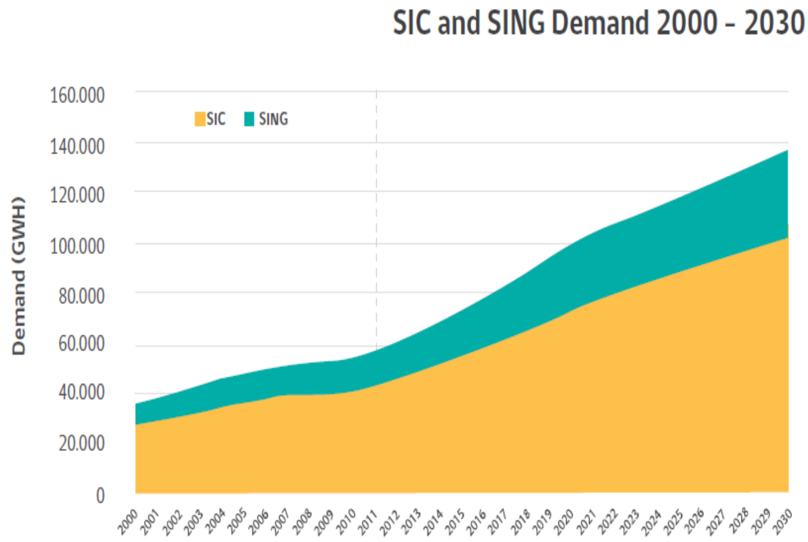

Figure III-2: SIC and SING Demand 2000-2030[2]

The Chilean electric system has been developed in the last years with a marked trend in the use of fossil fuels as a source of primary energy. The low cost of coal has been the main driver for the total dependency of Chile on exporting fossil fuels and the carbonization of the Chilean electric system [31]. In the case of the SIC, the 2013 generation was formed by 38% hydropower (due to droughts in recent years), and 53% by thermal generation (mainly coal and natural gas). The remaining 9% was produced by renewable energies, mainly wind and solar energy [32]. This composition of the sources of electric generation and the dependency of Chile on exporting fossil fuels, have also caused a rise and volatility in energy prices [31] (See Figure III-3).

It is important to remark that despite the low cost of coal, also in the case of Chile, coal power generation presents negative externalities associated to global and local pollutant emissions [33]. Furthermore, Chile has recognized its vulnerability to climate change due to its main productive activities [34].

Notwithstanding the above, Chile is not a major emitter of GHGs in the global context. Considering only CO_2 emissions from combustion of hydrocarbons, Chilean emissions are about 0.2% of the world emissions, ranking at 61st in the world ranking for per-

[2] Source: Chilean Ministry of Energy. National Energy Strategy 2012 - 2030.

capita- CO_2 emissions in 2008, with a value of 4.35 t CO_2/capita [34-36]. This percentage has remained constant during the last years, but the country's emissions are increasing significantly, mainly due to their growth in the energy sector [34,36].

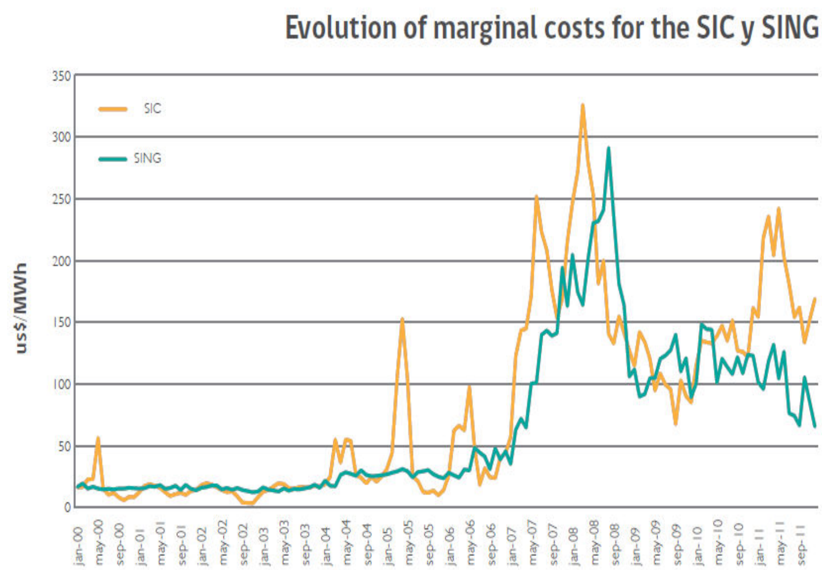

Figure III-3: Evolution of Private Marginal Cost for the SIC and SING[3]

Because of all mentioned above and considering the following:

- The importance of having abundant energy at the lowest possible price to achieve higher levels of growth of countries, especially developing countries like Chile;
- The projections of energy demand in the coming years and the expected growth in its consumption, particularly in the Chilean electricity sector;

[3] Source: Chilean Ministry of Energy. National Energy Strategy 2012 - 2030.

- The use of fossil fuels as primary energy source for the generation of electricity in many countries and their dependence on the international production, as the Chilean case;
- The GHG emissions, particularly CO_2, due to the significant use of more polluting energy sources like coal, natural gas and oil,

It is essential to encourage more efficient use of energy, to introduce new & cleaner forms to generate electrical energy at competitive prices, reducing the emissions of GHG. Thus, the design and assessment of incentives to the incorporation of energy efficiency measures is presented in this thesis.

1.1 Incorporation of energy efficiency measures

The Energy Efficiency (EE) can be understood as all the changes that result in a reduction in the amount of energy used to produce one unit of good or service or, in the same sense, to reach the energetic requirements for a given level of comfort. To this extent, EE can decrease the rate at which energy is consumed [37]. In simple terms, Energy Efficiency can be defined as a set of actions that optimizes the relationship between the amount of energy consumed and the quantity of final products and services obtained [12].

Today many countries are implementing initiatives aimed at promoting a more efficient use of energy in different sectors. There are various mechanisms to promote EE. Among them can be mentioned, flexible electricity pricing systems; labeling of products such as appliances and automobiles; establishment of energy consumption standards in manufacture equipment and air conditioning; energy management processes; replacement of luminaries; old buildings reconditioning; improvement in construction's materials; and EE information and training programs.

Yet, it must be taken into account that the effects of these measures depend on price elasticities, which can vary considerably between one industry and another [38].

Along the same line of thought, [38-44] it is relevant to point out the possibility of having a rebound effect. So, while the expected effect should be a rational decrease in energy consumption, in opposite, the increases in technology efficiency from the energy point of view may determine an increase in global energy consumption because of a larger aggregate consumption demand [38-44]. As Herring [45] points out: "Advocates of energy efficiency acknowledge that some of the savings from efficiency improvements will be taken in the form of higher energy consumption—the so called 'take-back' or 'rebound' effect. However, there is still intense dispute about its magnitude. It is strongly argued that it is much less than 100%; perhaps in the order of 10–20%."

As well, Laitner [46] states: "Depending on the assumptions of income and price elasticities, as well as the supply/demand interactions within a macroeconomic model, the rebound effect might reduce overall savings by about 2 to 3% compared to a pure engineering analysis. In other words, an economy-wide, cost-effective engineering savings of 30% might turn out to be only a 29% savings from a macroeconomic perspective. Despite the impact of a rebound effect, the net result of energy efficiency policies can be a highly positive one."

Therefore, incorporating measures to encourage a more efficient use of energy can achieve positive results despite the possible rebound effect decreasing EE projections achieved by a mechanism designed to promote them. Generally speaking, the ultimate goal of EE measures is to produce a market transformation that is capable of producing a decoupling between economic growth and energy consumption, reducing the dependence on fossil fuels as a primary energy source, and reducing greenhouse gas emissions. [15,26-28]. Thus, in this context, EE plays a key role contributing to achieve these aims [47].

In this context, some authors have reported the way some countries have worked in the promotion of EE as a measure not only to minimize the influence of energy use on climate change, but also with the objectives of maximizing the local air quality; minimizing the financial risk, the investment costs and the impacts of building new power plants and transmission infrastructures; and maximizing the security of energy supply [5,15,17,24,47-55]. So, in this context, governments around the world have developed policy frameworks to increase the role of EE in meeting new energy demand. For instance, the Japanese government in the last few decades has been implementing an energy conservation policy to achieve EE aims, largely motivated by global warming and CO_2 emissions reduction, both important issues around 1990. Since then, EE has been one of the most useful methods to achieve the goals of the Kyoto Protocol [54]. In the same manner, promoting the efficient use of energy has received a lot of attention in the European Union (EU). This has been an important policy objective for the EU members since the "oil shocks" in the 1970s, energy savings became relevant in the context of high oil prices leading to reductions on energy import dependence and GHG emissions [49,51,56].

Meanwhile in Latin America and the Caribbean, some measures were taken to promote EE. In most countries regarding care and dedication to this issue, an improvement can be seen mainly due to the belief that climate change is a reality and that one of the most effective ways to contribute to its mitigation is by implementing cost-effective energy efficiency policies [57]. For example, between 2008 and 2013 some progress have been made in the policy, regulations and institutional framework in most countries of the region, among which may be mentioned: the official publication of laws related to the efficiency energy in Uruguay (2009), the Bolivarian Republic of Venezuela (2011) and Panama (2012), where a law forming a trust to finance energy efficiency projects is also included in the case of Uruguay. In Peru (2007) a Supreme Decree regulating the Energy Efficiency Act was dictated; while Guatemala, El Salvador, Nicaragua, Dominican Republic and Granada are working on the preparation of EE draft laws. In addition, other parts of the region have been creating or strengthening institutional actors dedicated to energy efficiency, such as Energy Development Deputy Minister in charge of EE in Bolivia (2007) and the Bolivian Network Energy Efficiency (April 2013); the Ministry of Popular Power for Electricity in the Bolivarian Republic of Venezuela (late 2009); Chilean Agency for Energy Efficiency in Chile (2010); the National Office for the Rational Use of Energy in Cuba; the Colombian Council of Energy Efficiency (private sector, Colombia, 2010), the Ministry of Environment, Energy and Mares (MINAEM) in Costa Rica (August 2012), among others. Each one verifying the tendency to install or strengthen national efficiency energy programs through the legal and regulatory support.

However, despite the progress made in recent years, there are certain barriers to the systematic development of EE activities and programs [57], among them:

i. There is not, in general terms, enough knowledge about what actions can be taken to improve energy use and its consequent economic benefit, especially in the residential sector.
ii. Adequate indicators have not yet been developed, indicators that reflect the evolution of EE programs or projects and show the concrete results of the measures implemented on the region.
iii. In some countries the electrical tariff system, does not represent adequately the cost of generation, transport and distribution of electric energy, especially to residential sector.
iv. The companies of generation and distribution of electric and fuel energy have not been involved enough in EE programs.
v. Some countries have assigned more institutional emphasis in the areas related to environment / climate change than EE, considering energy efficiency as a mere appendage of environmental policies.

The barriers mentioned above are also present in Chile, to a greater or a lesser extent. This fact is the reason why this thesis shows the work done in this field, as a contribution to decline these barriers and the development of a systematic promotion and incorporation of EE measures as part of a long-term energetic strategy. It should be noted that the work done and presented in this thesis, has followed a definite pattern by developing three research articles and contribution to scientific knowledge which aim to advance the state of the art regarding the design and assessment of incentives to the incorporation of energy efficiency measures. Thus, three articles have been generated: one published and two in state of assessment, by widely recognized international journals in the Energy field, with the main participation and authorship of the creator of this document. Each of these papers has addressed various aspects or lines of actions aimed at reducing the aforementioned barriers.

In the first line of action, concerning the barriers mentioned in paragraphs (i) and (ii) a methodology for impact assessment of EE programs (with special emphasis on the indirect impacts) has been designed. This was the first course of action because EE can not be improved in the long term if there is not enough knowledge about what actions can be taken to improve it and what are its effects and benefits, especially in the residential sector where is necessary to consider that the promotion of EE requires focus on both quantitative and qualitative aspects and therefore on its impacts both short and long term. Thus, it is important to the promotion of EE that the effects achieved by the implemented measures are evaluated taking into account the direct and indirect impacts obtained. Consequently it is expected to advance in overcoming existing barriers by designing and applying a methodology that assesses both types of impacts, but with special focus on the indirect impacts of the programs and measures of EE.

It is important to note that, in general terms, this issue has been addressed in a different way to the one worked on this thesis. A methodology has been developed trying to advance to the estimation of the long-term impacts and cultural changes required for sustainable promotion of EE, by defining three axes: Presence, Valuation and Mobilizing capacity.

Thus, to the extent that understanding and measuring the indirect aspects of EE programs improve. It will be possible to generate better EE mechanisms designed to provide people adequate information and training to achieve cultural changes which will favor a more efficient energy use and a lower demand sustainable over time, improving in this way the effectiveness of quantitative EE programs, and their direct impacts on the economy and the environment.

Therefore, this methodology allows to evaluate the impacts of each EE program implemented and to detect relevant variables that must be considered in the design and implementation of future EE programs. In order to increase their cost effectiveness, especially of long-term, the objective of these programs is to generate transformations of energy markets through increased information and training in this issue, encouraging residential consumers to change their behavior regarding the use of energy in a way that can be maintained over time. This work is presented in the paragraph: Impact assessment of EE programs.

In the second line of action, concerning the barriers mentioned in the paragraphs (iii) and (iv) a symmetric flexible pricing model, type Time Of Use (TOU) is proposed. This flexible pricing model was designed for the residential sector of the main Chilean electric system, SIC. This tariff scheme was defined to minimize the cost of operation of the system, allowing both: transmission of price signals to encourage residential consumers to make their consumption decisions according to actual energy cost that they receive (promoting the implementation of EE measures in this sector) and the provision of incentives for electric distribution companies (DISCO) to participate in a major way in promoting these EE measures. This work also estimates the benefits for the distribution companies compared to the base case depending on the level of simulated consumer response that will depend on the effectiveness of EE measures that can be adopted by residential customers. This work is presented in the paragraph: Symmetric TOU in SIC.

In the third line of action, concerning the barrier mentioned in paragraph (v), the effectiveness on reducing CO_2 emissions in the SIC, through a carbon tax of 5 $ / Ton CO_2e is evaluated. The recent implemented measure by the Chilean government with the aim to reduce the CO_2 emissions was compared with the implementation of EE measures in the residential sector depending on the level of simulated consumer response. In this way information is generated to evaluate strategies, carbon tax and EE measures, in the context of environmental policies. This work is presented in the paragraph: Measures to reduce CO_2 emissions in SIC.

These three lines of action are designed to help reduce the barriers identified in subparagraphs (i) to (v) and therefore contribute to the promotion and incorporation of EE measures. First, the methodology allows evaluate direct and indirect impacts of EE programs and estimate its effectiveness. Further, it allows estimate the program's contribution to the necessary cultural changes and identify key variables to improve the design and application of EE programs depending on its target public. Thus it can improve consumer response and therefore the effectiveness of EE programs both to achieve greater efficiency in energy use and the reduction of emissions of greenhouse gases. Secondly and with these considerations the design of a flexible electricity tariff that considers the profiles of electricity consumption and generation costs each node of SIC is presented. The profits estimated of this tariff scheme are compared with those obtained in the base case, depending on the level of demand response simulated. Similarly, and thirdly, a comparison of the effectiveness of carbon tax recently implemented by the Chilean government and EE measures to reduce CO_2 emissions and their effects on the average marginal cost of SIC is presented, depending on the level of demand response obtained by the EE measures.

Below a diagram that shows the relationship between the identified barriers and the work done in this thesis is illustrated. (See Figure III-4)

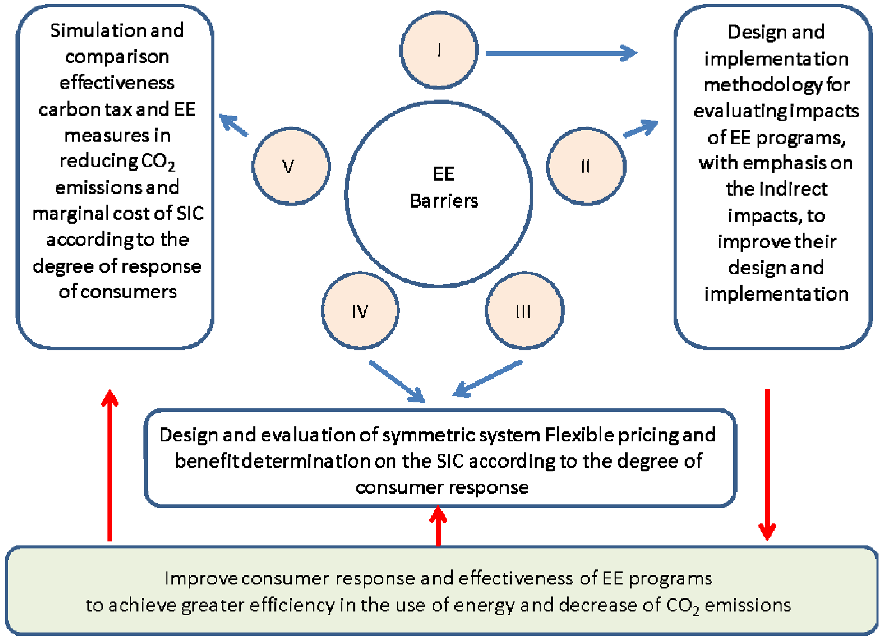

Figure III-4: Relationship between the identified barriers and the thesis work

1.2 Hypotheses

Research Hypothesis: Energy efficiency can be encouraged through different mechanisms. The design of these mechanisms will achieve global and specific results that can be assessed through its direct impacts achieved in the short term (as reducing energy consumption) and also through its indirect impacts that achieve market transformations and promote sustainable effects in the long-term on the efficient use of energy.

1.2.1 Secondary hypotheses

i. Measuring the direct and indirect impacts generated by mechanisms designed to promote EE allows on one hand, to know the effective reduction in the consumption of the energy produced by this mechanism and, on the other hand, to identify some relevant variables that should be considered in designs and redesigns of mechanisms promoting EE.
ii. There are different mechanisms that can be designed to promote EE. Some of them may be general, as programs of information or education or more specific as the design of an electrical tariff' scheme for a city, which allows flattening the demand curve and reduce its picks and investment in capacity.
iii. Finding the best alternative to reduce CO_2 emissions requires consideration of the specific characteristics of each country or region. Thus, the goal of reducing GHG emissions can be achieved without significantly affecting other relevant variables such as energy prices.

1.3 Objectives

The main objective of this thesis is to study and evaluate the design of some measures to improve the efficient use of energy in Chile. Therefore, the following questions must be answered: What would be the implications of the implementation of some mechanisms designed to encourage energy efficiency in Chile? How might these implications be measured, considering both direct and indirect effects, and the characteristics of developing countries like Chile?

1.3.1 Specific objectives

i. To analyze some methodologies used in Chile for evaluating impacts of the public program and also some methodologies evaluating impacts of EE programs worldwide, considering their applicability and convenience for an organization (public or private) of a developing country. In this case, applicability and convenience of these methodologies are understood on the basis of their simplicity of use, the amount of monetary and human resources to be allocated for their proper application and the diversity of programs and projects of EE to which they can be applied.

ii. To design an impact evaluation methodology of EE programs, ad-hoc for developing countries like Chile, to assess both direct and indirect impacts of EE programs in order to be applicable to different types of EE programs, with the flexibility to be applied in a modular manner and the simplicity so as not to demand excessive human and monetary resources in its application.

iii. To apply the designed methodology on some EE programs developed in Chile, in order to obtain relevant conclusions for future designs of mechanisms to promote EE.

iv. To design a model to generate a flexible tariff system of the Time of use (TOU) type, in order to maximize total income of Distribution companies (DISCOs), while guaranteeing minimum system cost. It is based on the load curve data in a electrical consumption node and historical prices of the energy in that node.

v. To propose and evaluate a symmetric TOU system for electricity consumption in some nodes of the main Chilean interconnected power system (SIC) simulating different response from consumers and estimating the corresponding economical benefits.

vi. To compare the effectiveness of reducing CO_2 emissions on the SIC of a carbon tax of 5 \$/Ton CO_2e and EE measures implemented on the residential sector in this electrical system.

1.4 Main contributions of the Thesis

i. Design of an impact assessment methodology of EE programs, to evaluate both direct and indirect impacts of EE programs. With special focus on indirect impacts through three axes: Presence, Valuation and Mobilizing capacity. The design criteria were: *applicability* for different types of EE programs, *flexibility* to be applied in a modular manner and *simplicity* so as not to demand excessive human and monetary resources in its application.
ii. Application of the designed methodology of impact evaluation to 12 EE programs of the Chilean Energy Efficiency Agency (AChEE, for its acronym in Spanish), implemented during 2011 and 2012, in order to obtain their indirect impact assessment.
iii. Formulation of a model to generate a flexible tariff system, of the Time of use (TOU) type in order to maximize total income of Distribution companies (DISCOs), while guaranteeing minimum system cost, based on the load curve data in a electrical consumption node and historical prices of the energy in that node.
iv. Development of a case study of a symmetric TOU system for electricity consumption in some nodes of the main Chilean interconnected power system (SIC) simulating different response from consumers and estimating the corresponding economical benefits.
v. Comparison of the effectiveness of reducing CO_2 emissions on the SIC of a carbon tax of 5 \$/Ton CO_2e and EE measures implemented in the residential sector, in order to provide information to improve decisions in environmental field.

1.5 Impact assessment of EE programs

Today many countries are implementing initiatives aiming to promote a more efficient use of energy in different sectors. There are various mechanisms to promote EE. Among them: flexible electricity pricing systems; labeling of products such as appliances and automobiles; establishment of energy consumption standards in manufacture equipment and air conditioning; energy management processes; replacement of luminaries; old buildings reconditioning; improvement in construction's materials; and EE information and training programs.

Generally speaking, the ultimate goal of EE programs is to produce a market transformation that is capable of producing a decoupling between economic growth and energy consumption, reducing the dependence on fossil fuels as a primary energy source, and reducing greenhouse gas emissions. Consequently, measuring the long-term market transformation effects of EE programs is crucial. Moreover, when public monetary resources are used to implement those EE programs, the assessment of these market transformation effects are even more relevant.

However, in the current literature and practice, most methodologies assessing the effects of EE programs have only focused on direct impacts (i.e., impacts whose energy savings can be directly quantified) due to their objectivity and simplicity to put evaluations in a cost-effectiveness framework. For instance, Henriksson and Söderholm [58] rank EE programs according to the energy savings obtained from a cost-benefit analysis, considering only the direct short-term effects of the programs.

Although some authors as Blumstein et al. [59], recognize the existence of indirect impacts of EE programs, the assessment methodologies used by them basically focused on identifying the effects and, at most, quantifying a proxy of the effects in terms of the number of activities developed or the number of people attending EE training or dissemination events.

In this work a methodology to assess the impacts of EE programs with special focus on indirect effects (i.e., effects not generating immediate energy savings) is proposed.

Specifically, the methodology focuses on those indirect effects having the capability of mobilizing long-term energy savings through market transformations in energy markets. It attempts to measure the potential future energy savings that are sustainable in the long term due to a behavioral transformation of energy markets. In order to measure these indirect effects, three axes are used: *Presence, Valuation and Mobilizing capacity*. Contrary to common current methodologies, these axes allow collecting information regarding people's levels of knowledge and perception of EE and regarding the usefulness of different EE mechanisms in people's domestic tasks. Availability of this information is a pre-requirement to transform energy markets, make a more sustainable use of energy over time and generate a suitable base that reinforces future EE actions that can be quantified in terms of effectiveness reducing energy consumption associated with certain levels of services received.

This impact assessment methodology has been designed considering as criteria of design, the *applicability* to different types of EE programs, *flexibility* to be applied in a modular manner and *simplicity* so as not to demand excessive human and monetary resources in its application.

1.5.1 Review of impact assessment methodologies of EE programs

In the current literature, most methodologies for assessing the effects of EE programs have focused on direct impacts due to their objectivity and simplicity to put evaluations in a cost-effectiveness framework. Henriksson and Söderholm [58] rank EE programs according to the energy savings obtained from a cost-benefit analysis, considering only the direct short-term effects of the programs. Boonekamp [60] concludes that most of the time EE is evaluated in reference to direct consumption reductions, i.e., based on the direct impacts. Cui et al. [61] review different methodologies to evaluate impacts of EE, concluding that these methodologies, in general, have focused their attention on calculating direct energy savings and identifying some influencing factors in the results.

The reason, according to the authors, is that EE is defined as efficiency, which implies it must reflect an immediate input-output efficiency gain regarding the energy use. Similar conclusions are provided by Zhou and Ang [62] by analyzing different models to measure EE impacts. In the same direction, Gabardino and Holland [63] remark that there is a trend in the impact assessment methods to prioritize quantitative measurement of impacts, mainly because quantitative methods produce data that can be aggregated and analyzed to describe and predict relationships among them. However, they recognize qualitative studies may significantly help in explaining contextual differences in those relationships.

Several other authors have pointed out the importance of considering the indirect effects of EE programs. Blumstein [64] recognizes the significance of measuring indirect impacts of EE programs and claims that investing in programs with mostly direct impacts and investing in programs with mostly indirect impacts are complementary strategies. Vine [65] remarks that sometimes evaluators focus on direct effects of EE programs because they are ease to measure, forgetting the true program goals (which are often harder to measure). This situation frequently occurs in EE education programs. Van Den Wymelenberg et al [66] pointed out that EE programs can have some components that involve market transformations that aim to change behavior of individuals and organizations. They recognize that these components are complex and expensive to evaluate, when compared to traditional direct methods, because they require determination of changes in behavior, attitudes, and process development, among others. In the same sense, Palmer et al. [67] also recognize the significance of measuring the indirect impacts of EE programs and point out the need to consider separately an EE impact evaluation, a process evaluation and an evaluation of the market effects. In addition, Boonekamp [60] also recognizes that socio-economic characteristics and demand evolution should be considered in an adequate assessment methodology through use of statistical information.

In Chile until 2012, there were several general methodologies for impact evaluation of public programs, but none of them were specifically designed for evaluating EE programs. Recently, in 2013, the AChEE adopted the International Protocol of Measure and Verification, IPMVP [68], as the official methodology to assess the direct impacts of its EE programs. However, there were not assessment methodologies to evaluate the indirect effects of EE programs before this work. Previously, the indirect effects of EE programs were evaluated by adapting other assessment methodologies (that were designed to evaluate other type of public programs). The main two assessment methodologies previously used in Chile to evaluate the indirect effects of public programs are the methodology designed in 2009 by the Chilean Budget Direction [69], DIPRES, and the Logical Framework methodology presented and systematized by the Latin American and Caribbean Institute for Economic and Social Planning [70], ILPES.

The methodology used by DIPRES [70] was created with the aim of measuring the effectiveness of the outcomes at different levels, considering issues of efficiency and economy of the public programs evaluated. It was oriented to government agencies that are in charge of the design, implementation, monitoring, control and evaluation of programs with public funds. As a tool, it considers the evaluation of quantitative and qualitative variables and it raises the need for assessment and measurement of short-, medium- and long-term effects. It defines three levels of outcomes to assess: Product Level, or short-term results, Intermediate Level, or medium-term outcomes related with the changes in behavior, skills and abilities (that is, the formation of human and social capital), and Final-Results Level or Impact Level, which refers to those effects achievable in the medium and long term. The main advantages of DIPRES's methodology for assessing impacts of EE programs are its applicability to a wide range of public programs and the consideration of assessments at different levels of results and moments in time. However, an important disadvantage is the large request for information of the programs, individuals and organizations both participating and not participating (control groups) in the programs. These massive information requirements translate into significant cost, which may represent a significant fraction of the total budget of the program itself in cases of small programs or low-budget programs.

On the other hand, the Logical Framework methodology is defined as a tool to support the processes of planning, monitoring and evaluating projects and programs. The core of the methodology is a clear and explicit definition of strategic objectives or main goals to be achieved through the implementation of the program or project. The methodology facilitates the process of conceptualization, design, implementation and evaluation of projects and programs, with a strong orientation to the definition of objectives delineating the project activities in any of their stages. It includes steps for identification, preparation, assessment, monitoring and control of the projects. The main advantage of the Logical Framework methodology is that it is focused on the coherent definition of programs and evaluations. On the other hand, its main disadvantage for evaluating EE programs is that it could be very costly in human and financial resources, because it is very intensive in time dedication for planning activities, especially for pilot programs.

Meanwhile, several assessment methodologies are used worldwide to evaluate the impacts of EE programs. The most commonly used in the US are the International Protocol of Measure and Verification, IPMVP [68], the Model Energy Efficiency Program Impact Evaluation Guide [71], The California Evaluation Framework [72], The California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals [73] and The EERE Guide for Managing General Program Evaluation Studies and Impact Evaluation Framework for Technology Deployment Programs [74].

The International Protocol of Measure and Verification, IPMVP [68], is a guide that presents a framework and four measurements and verification (M&V) options for reporting of energy savings, thereby allowing a project to be transparent, accountable and coherent. The M&V activities considered are: analysis of the facilities, energy metering, monitoring of independent variables, and the calculation and reporting of energy savings. IPMVP [68] has been proposed as a guide for professionals who must necessarily get involved in a prior design M&V Plan. The main advantages of IPMVP [68] are that it provides specific methods for evaluating projects in the EE field and that it reduces information asymmetries among the actors by permanently adopting it as part of the evaluation methodology. On the other hand, some disadvantages are the facts that it requires full adoption of this guide to use it as a reference, it applies only to direct impacts and it includes additional implementation costs associated with the management and control of the guide itself.

The Model Energy Efficiency Program Impact Evaluation Guide has been developed to assist the implementation of the National Plan for Energy Efficiency of the Department of Energy of the US [74]. This guide describes several models to calculate energy savings, demand for energy and global emissions, which can be applied to EE programs that are implemented at state, city or company level in the US. This guide recognizes that there are different types of EE programs and proposes three types of ex-post assessments: impact evaluation, process evaluation and evaluation of market effects. The main advantages of this methodology are that it provides specific methods for evaluating projects in the EE field and it is based on the implementation of the IPMVP [68] as part of the evaluation. Its main disadvantages are that it requires full adoption of the methodology if you want to use it as a reference, it requires a communication plan that allows program managers and evaluators to develop and communicate a clear understanding of the methodology, and it must consider the costs associated with management and control of its implementation.

The California Evaluation Framework [72] has been prepared by The California Public Utilities Commission and the Project Advisory Group. It provides a consistent, systematic and cyclical planning and it establishes the basis to perform evaluations of the EE programs in California. The design considers the review of some assessment protocols used in California or other places. This framework was designed to serve as a roadmap, providing practical guidance to program managers in order to plan their assessment efforts consistently with the needs of the CPUC and other stakeholders programs. It also facilitates comparison among the effects of different programs by measuring them. This methodology can be used in the assessment of direct and indirect impacts. In the first case, the purpose is to verify energy savings reached directly by the program while in the case of indirect impacts, it is recommended to establish a baseline in order to study and compare them with a post-measure study to evaluate the effects of the program. Its main advantage is that it defines a comprehensive framework to assess different types of programs, and its main disadvantage is the high requirement for monetary and human resources to implement the methodology.

The California EE Evaluation Protocols [73] were prepared in 2006 by CPUC and the Project Advisory Group in order to be a guide to evaluate the California EE programs that started in 2006. These protocols are based on the California Assessment Framework and cover assessments of direct and indirect impacts, including effects on the market, emerging technologies, codes, standards and processes. Its main advantage is that it constitutes a detailed and specific protocol for EE programs evaluation. As well, its main disadvantage is the high requirement for monetary and human resources to implement the protocols.

The EERE Guide for Managing General Program Evaluation Studies divides the process of program evaluation in 14 steps very easy to understand. These steps are grouped into two major phases: (i) planning and design of the evaluation and (ii) management and dissemination of evaluation results. Its main advantages are that it helps to have a notion of the program's performance based on their goals and that it can be applied to a wide range of programs. However, its main disadvantage is that it does not contribute significantly to the development of specific evaluation plans because it assumes that this is task of the consultants running it.

As it is seen here, most methodologies or protocols focused mainly on the assessment of the direct impacts of the EE programs, although some of them recognize the need for orienting the evaluations to measure indirect impacts. Generally speaking, all these methodologies expect reporting and measuring the effects of the EE programs and, in this way, allowing the verification of goals, helping to understand why effects happen, identifying ways to improve current programs, and helping in the selection of future programs. Most of these methodologies are intended to evaluators and professionals that are involved in the design and evaluation of EE programs and thus their objectives are to increase cost-efficient investment in EE projects through minimizing information

asymmetries associated with the results of these projects. In some of these protocols, the existence of different types of programs is recognized (resource acquisition, market transformation, codes and standards, education and training, and multiples targets).
From the point of view of their applicability in developing countries, the main advantage of these methodologies is the consideration of specific methods to evaluate projects on the EE field. Their main disadvantage, however, is that they generally require full adoption especially if used as a reference, which may represent a budget problem. Nonetheless, in some cases where a win-win situation can be achieved EE measures may be carried out by programs funded by governmental institutions as a way of improving social welfare [75]. In those programs, it is fundamental to generate policy guidelines, instruments and energy programs that facilitate the coordination among different players in the industry, including consumers, producers and government authorities [76].

1.5.2 Design of a methodology to evaluate the impacts of EE programs

After reviewing some existing methodologies for evaluating direct and indirect impacts, a methodology for evaluating EE programs with special focus on those indirect effects is proposed; having the capability of mobilizing long-term energy savings through market transformations in energy markets. In order to measure these indirect effects three axes will be used: Presence, Valuation and Mobilizing capacity. The proposed methodology also considers relevant aspects for its application in developing countries (such as the impact assessment of programs implemented as a pilot, low budget for their implementation and evaluation, and the applicability to a wide range of programs and types of interventions). Accordingly, the design of the methodology for assessing impact of EE programs is based on the following criteria: Applicability, defined as its ability to be applied to different types of EE programs in various sectors of the economy, and to measure both direct and indirect impacts; Flexibility, understood as its ability to be applied in a modular fashion either to complete programs or some of their components,

or to each of the projects associated with the implementation of the program; and Simplicity, defined as the ability to establish itself as a practical and detailed guide, easy to apply to different types of EE programs. Thus, the ultimate goal of this methodology is to promote the proper evaluation of the results of EE programs with direct and indirect impacts, in order to generate reliable information to support decision makers regarding the effectiveness and continuity of programs, as well as, regarding the feedback design process and the implementation of instruments that promote the efficient use of energy.
The methodology is contextualized in a general framework. This framework has three different levels: strategy level, program level and evaluation level. Since the methodology is especially focused on the evaluation level, only a brief description of the strategy and program levels are provide here.

General framework of the methodology

The proposed methodology is developed in a general framework, basing the programs and their evaluations on the strategic objectives and guidelines of the institution that will carry them forward. This general framework is composed of three parts: Strategy Level, Program Level and Evaluation Level (see Figure III.5)

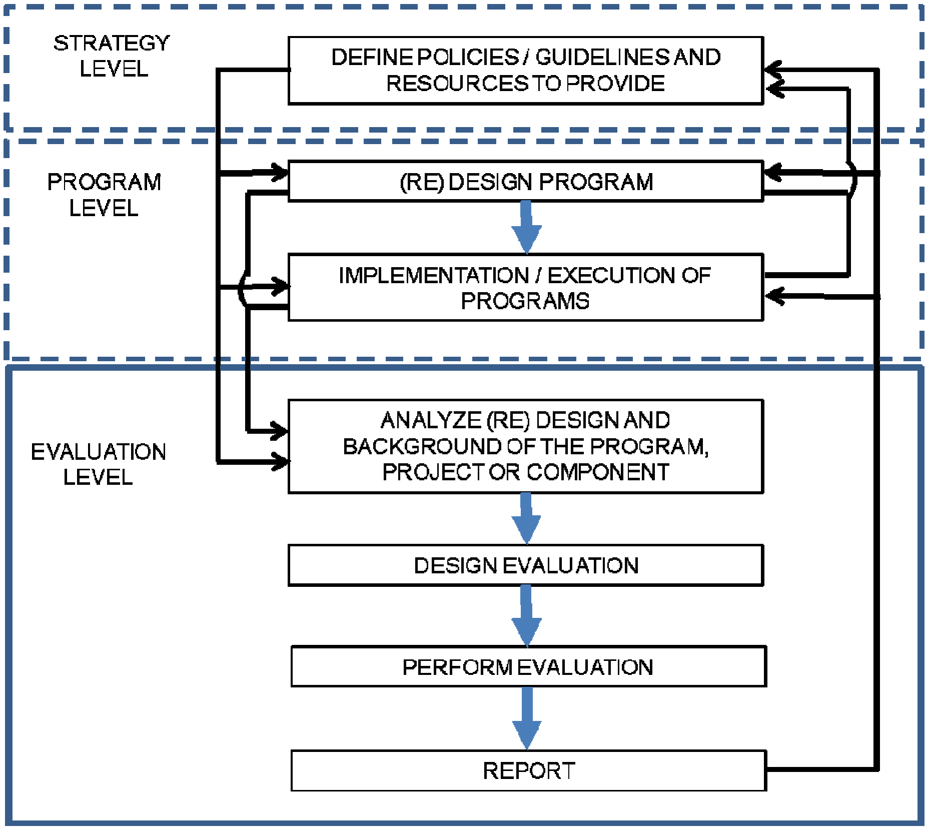

Figure III.5. General framework of the methodology for impact evaluation of EE programs

The Strategy Level consists of all actors, functions and processes that define and deliver policies and strategic guidelines for EE programs and projects to be developed. Consequently, EE programs must be evaluated in view of their consistency with those policies and strategic guidelines. This level also provides resources for the design, implementation, execution and evaluation of these programs and projects. Thus, this level provides inflows to the processes carried out at both program level and evaluation level, which are represented by the arrows in the left-hand side of the diagram in Figure III.4. Moreover, the level of programs, feeds this level from the information generated in its processes of design, implementation and execution, as well as by the level of evaluation, using information generated from the results of impact assessments. This information flow is represented by arrows on the right-hand side of the diagram in Figure III.5.

The Program Level considers the design and redesign, implementation and execution of programs. It obtains information and resources from the strategy level, providing information to the evaluation level through reports and the experience gained in these processes, and the evaluation level feeds it with the information generated as a result of the assessment. These information flows are explicit by the arrows on the right- and left-hand sides of the diagram in Figure III.5., respectively. At this level, it is highly recommended to develop the design of the program considering the definition of a theoretical framework that provides support and coherence to the program itself, its goals and activities. As well, it is suggested developing a preliminary design of the evaluation at this level, so processes and activities are prepared and executed in such a way that the assessment of the impact is facilitated and the results have the highest possible level of reliability given the available resources.

Both the strategy and the program levels have been included in areas delimited by dotted lines in Figure III.5., representing that the design of the methodology of impact evaluation does not include the processes developed inside them. Instead, the scope of the proposed methodology includes only the processes occurring within the evaluation level.

The Evaluation Level considers the core processes of this methodology, comprised of four basic steps that are fed with information from the strategy and program levels. These four steps also provide feedback to the previous (more strategic) levels. These four steps are assumed sequentially for purposes of description of the methodology and, therefore, they have been connected with unidirectional arrows in Figure III.5. However, each of these steps can go down to another if necessary. The following subsections describe these four steps proposed to be considered in the evaluation level.

Step 1. Analyze the design and background of the program, project or component

In this step, an analysis is carried out of all relevant information regarding the design and implementation of the program, and the preliminary design of the evaluation, if it exists (see Figure III.6.).

This step contains a review and analysis of the description of the program, project or component to be evaluated and an analysis, if it is possible, of the theoretical model giving foundation and coherence to the objectives, activities and program goals. In the absence of the theoretical model, the evaluator should generate it based on their experience and the information available. This first step also considers the identification of the objectives and desired effects of the program, as well as the goals, indicators and variables declared in the program design. In this way, it can be clearly established the questions the evaluator wants to answer through the impact evaluation. This step also includes an analysis of the causal relationships originated by the program and determines the activities developed. The identification and characterization of the relevant program variables, both present in the causal relationships and those that are not present, are also considered in this step. Some variables that are not present in the causal relationships are included because they can be a source of distortion of the obtained results. This step also includes a review of the preliminary impact evaluation guidelines defined in the program design, if it exists, regarding the implementation and final execution of the program. Finally, the step considers an analysis of any other aspect of the design or implementation of the program, project or component that provides important background information that must be taken into consideration in the design and implementation of the evaluation.

In this way a description of the program is generated, that includes a clear definition of the goals, objectives and strategies associated with the program, project and/or component, and the way the program was designed and implemented to achieve the proposed goals. This description facilitates the subsequent design of the evaluation plan because it helps to identify the issues that need to be evaluated, how the evaluation should be carried out and the best way to collect the required data, depending on the type of program to be evaluated. One way to accomplish this description of the program is by using the theoretical framework of the program, in case that the program design includes it. Otherwise, the theoretical model of the program must be defined at this step of the evaluation, making explicit the causal relationships among its different elements and the goals to achieve with the program. This theoretical framework should be built at the program level, at the design or redesign stage.

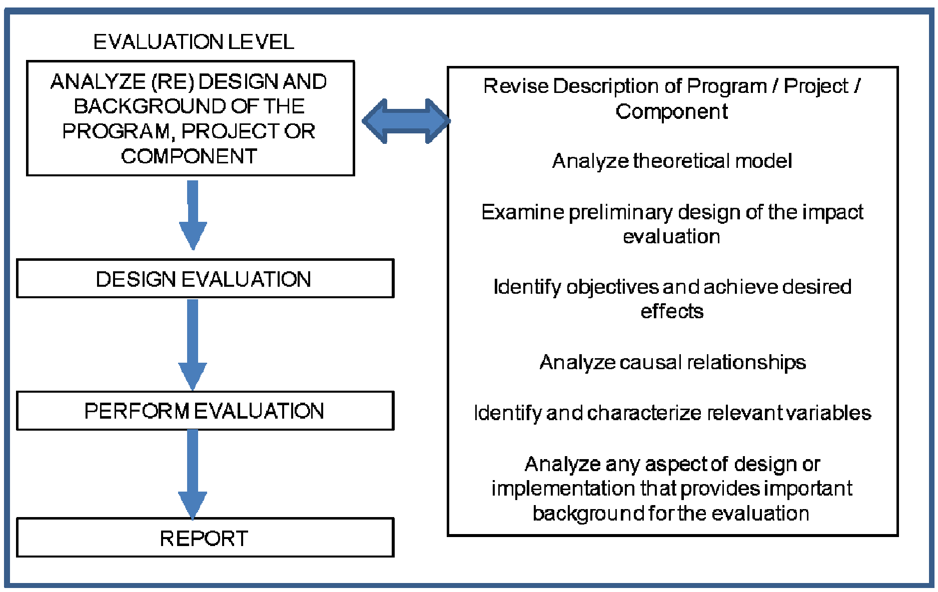

Figure III.6. Step 1.Analyze the design and background of the program, project or component to evaluate

Step 2. Designing the program, project or component evaluation plan

At this step, the final design of the evaluation plan is developed. This plan must define the evaluation objectives, identifying the questions to be answered in the evaluation (e.g. what is the objective of the evaluation? What type of results is expected to obtain? How will the results be used? What is the relevance of the information to obtain?). The plan also sets the audience of the information, including its main features and requirements of both content and format and define the scope of the evaluation and the level of reliability of the results. These definitions must be coherent and consistent with the resources available for evaluation. Accordingly, here it is necessary to ask what information is required and what level of detail is required. In these questions, it should be considered that the results of the evaluation will be used to support the continuity and expansion of a program through verification of their impacts, or to support investment decisions to produce more energy saving, or to provide feedback on program design or some of its components to increase its effectiveness. Thus, the purpose of the evaluation carried out should be clearly stated, identifying key stakeholders and the sector to which they belong. Additionally, this plan must determine the resources available for the evaluation, including monetary, human resources, time, skills, etc. In particular, once human resources available for evaluation are established, the roles and responsibilities of each one of the agents involved should be defined. It is also required to determine the aspects and variables to assess, in order to design the evaluation plan. Being precise in these definitions is necessary because the results may have several uses and recipients. This implies carefully selecting the activities to be evaluated according to the objective of the evaluation plan and the theoretical framework that describes the program. In the case that the design and implementation of the program is being evaluated, an intermediate evaluation may be conducted, corresponding to a process evaluation where those activities that lead to the achievement of the overall goals of the program are evaluated and where there is a focus on the target audience interest. Finally, this plan must select the measuring methods to be used according to the type of program, project or component and the type of variables to be measured. This task includes identifying the questions to answer and metrics to use, defining indicators, according to what evaluators want to measure and the goals of the program, project or component; and scheduling the activities contained in the evaluation plan (see Figure III.7).

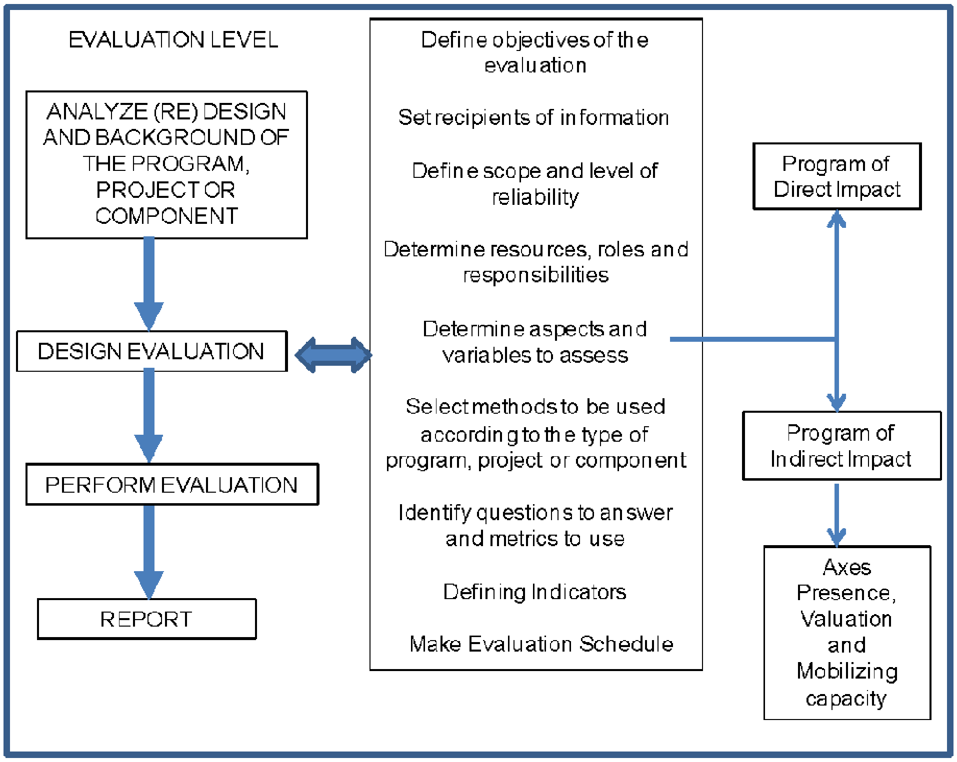

Figure III.7. Step 2: Design of the program, project or component evaluation plan

The objectives of the evaluation and the types of impacts measured.

Depending on the objectives pursued with the evaluation of a program or any of its components, the evaluation plan focuses on assessing direct or indirect impacts (or both). The main goal of a direct impact assessment is to obtain an estimation of the net energy savings achieved as a direct result of the program, project or component, in the most accurate and unbiased way possible, given the information available, the level of reliability of the required information and the resources that are available to develop the assessment. Since energy consumptions, and not energy savings, are truly measured. To determine the net energy savings, it is necessary to measure the change in the energy use of a system subject to a participant EE program through a certain period of time and then, estimate which would have been the energy consumption of the participant, in the absence of the EE program. Depending on the type of energy involved in the program, the net energy savings can be measured in terms of kWh, gallons of fuel, thermal units of gas, etc.

Different methods can be used to evaluate the direct impacts of programs. These methods can be classified in engineering methods and methods of billing analysis. The decision of which method to use should consider criteria such as the specific type of program, the available resources, data collection costs, the reliability level required for the resulting information, the size of the program, project or component to evaluate and the existence of similar evaluations previously developed. Engineering methods are preferred when there is no billing information before program implementation. This occurs, for example, when programs aim to promote EE in new buildings, facilities or technologies. Engineering methods are also recommended when it is expected that the effects achieved by the EE program were so small they are not distinguishable in billings. This usually occurs when consumption savings due to the program, project or component are less than 10% of the typical total bill, or when program participants are too heterogeneous. On the other hand, methods based on billings will be preferred when the data of the corresponding bills before and after the program implementation are available, when estimated program effects on savings are of a magnitude easily detectable from billings analysis, and when program participants are relatively homogeneous.

In the case that the evaluation plan focuses on assessing indirect impacts, existing assessment methodologies typically only identify and classify the effects and, at most, they propose to estimate the impacts by the number of participants in program activities such as the number of attendees at outreach or training activities or by the number of hours of courses taken. On the contrary, our methodology proposes the estimation of those indirect effects having the capability of mobilizing long-term energy savings through market transformations in energy markets. That is, attempting to measure the potential future energy savings that are sustainable in the long term due to a behavioral transformation of energy markets. In order to measure these indirect effects, we use three axes: *Presence, Valuation and Mobilizing capacity*. Thus, contrary to common current methodologies, these axes allow collecting information regarding the people´s levels of knowledge and perception of EE regarding the usefulness of different EE mechanisms in people's domestic tasks. Availability of this information is a pre-requirement to transform energy markets, to make a more sustainable use of energy over time and to generate a suitable base that reinforces future EE actions that can be quantified in terms of effectively reducing energy consumption associated with certain levels of services received.

Each of these three axes has dimensions and attributes by which it is evaluated. Its measurement is done through different methods of data collection (surveys, structured or semi-structured interviews, and focus groups, among others). In each data-collection method, appropriate questions should be selected depending on the characteristics of the method, the attribute to evaluate, and the interest group (IG)[4] to be evaluated. When constructing questions and metrics, it is important to recognize that some metrics will directly contribute to the reporting requirements of the organization for which the evaluation is made and some other metrics will only contribute in an indirect way. This is relevant because metrics directly contributing to the reporting requirements may be comparable over time.[5]

It is important to note that the metrics used should allow translating concepts into numbers, so the evaluation results are properly reported. For example, when a question is used regarding how often a person has spoken about certain program, the evaluator should establish ranges of answers classified from the most favorable to the most

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[4] The IG may be formed by participants or beneficiaries of programs, representatives of institutions or the government, etc. depending on the objective of the evaluation plan and the use of the information obtained therein.

[5] A common problem for evaluators is that measurements vary within each assessment, making difficult establishing long-term trends. Accordingly, it may be useful reporting common metrics across different evaluations of different programs, so program managers and evaluators can easily compare the performance of programs involving similar activities.

unfavorable results, which at the same time depend on the indicators defined in both the program design and the design of its evaluation.

Since this methodology focus on the assessment of the indirect impacts of EE programs or some of its components or projects, we now present a detailed description of the dimensions and attributes of each axis used to measure the indirect effects. For the same reason, the rest of the paper focuses on the indirect impacts of EE programs only.

Presence Axis

The presence corresponds to the way the EE program and its actions are present in the minds of people or IG associated with the program. This axis has two dimensions: notoriety and scope. The notoriety is measured by two attributes: penetration and intensity. Penetration is the amount of people who know about the EE program, while intensity is the amount of times the program is mentioned in a social setting or broadcast network. These two attributes allow estimating how notorious the EE program is. The type of questions used in an interview (or other data collection method) to get information about these attributes can be, for example: Do you know the program or technology? On average, how many times (number of interactions or social meetings) you talk about the program with colleagues or friends within a month?

On the other hand, the scope is measured by the number of interactions occurring among members of different layers of exposure to the EE program. Let’s define the “Core” as the set of people who are directly exposed to the EE program (i.e., who begin the diffusion process). Then, we define the “first layer” as the set of people who interact with people belonging to the core, the “second layer” as the set of people who interact with people belonging to the first layer, and so on. Thus, the scope is measuring how far people’s interactions can help positioning an EE program in people’s minds (starting from the core and moving towards the first layer, second layer, etc.). Naturally, the amount and quality of information is decreasing when moving out from the core. Some questions used to measure the scope of a program are: How many people have you told about the program last month? What do you generally say about the program?

Valuation Axis

This axis represents the value (degree of worthiness or favorable disposition) that the IG assigns to the EE program. This axis has four dimensions: context, relevance, identification and evaluation. Context means the framework in which the program is promoted, such as official events, seminars, workshops, etc. Some questions that can be used in this case are: What is the percentage of the audience that knew about the product or service offered through the EE program media used? What is the percentage of the audience that knew about the product or service offered through a friend's recommendation?

The relevance corresponds to the degree of significance of the program's purpose stated for the scientific research (academic community), public policy (government), production (firms) and daily consumption (people). Some questions that can be used to get this information are: How important is energy efficiency for you? How relevant is this program to help you in using efficiently the energy?

The identification is the degree of consistency between the EE program and the needs and expectations of each IG, regarding energy topics. Suitable questions in this case are: Which unmet needs do you have in the areas of energy efficiency? To what extent does the program take care of these needs?

Finally, the evaluation dimension corresponds to the positive, neutral or negative general assessment given to the program by the IG. In this case, some ad-hoc questions are: Are the attributes of the technology or process that you use more advantageous than the attributes of the technology or process used by your competition? Is the technology or process promoted by the program easy to install?, easy to use? Can the product or process that promotes the program be easily tested? Is it easy to see results of the use of this technology or process?

Mobilizing Capacity Axis

This axis refers to the intensity of the motivation of the IG to transfer the effects of the EE program to other people and, thus, it refers to the ability of the IG to motivate other people to perform the desired EE actions. This axis has two dimensions: movement and transcendence. The movement has two attributes: the persuasive capacity and the number of reactions to positive responses. The first attribute is the persuasive and convincing capacity of the message delivered by a promoter of the program to generate actions in the receptors; while the second attribute refers to the amount and type of specific positive reactions or responses that are triggered from the receivers of the message disseminated in the program. The types of questions suggested in this case are: What specific actions have you performed based on what you have learned in the program? If you had to recommend implementing this program to a person, what concrete actions will you recommend in order to maximize its use? How much your behavior regarding EE has been improved because of this program?

The transcendence meanwhile has four attributes: predisposition, perseverance, attitude and behavior. This dimension (and its four attributes) is related with the adoption of long-term behavior. Some suitable questions in this case (for the particular case of energy consumption, labeling for instance) are: Do you use the labeling information in the purchase decision process? How do you think this information will influence your future decisions? How much do you agree with the following statement: “It is important to look at the energy consumption when purchasing a vehicle”

Step 3. Performing the evaluation of the program, project or component

In this step, the evaluation plan is implemented according to the specifications in terms of what will be measured, how it will be measured, who will measure it, and when it will be measured. It is recommended to define a person in the plan that will be in charge of the "project evaluation". This person will be responsible for managing the evaluation and shall ensure the realization of all specified tasks and products associated with the evaluation and the expected outcome of the assessment. Furthermore, having a specific evaluation unit or an independent consultant for executing the evaluation plan is desirable. In this way, it is avoided that the evaluation is performed by designers, implementers and/or managers of the same program, ensuring objectivity and continuity of the process. Consistently with the above, in this step must be selected: the audience sampling, the methods applied and metrics previously defined, collected data, and the data analysis done (see Figure III. 8).

Step 4. Report of the evaluation results

This step consists of reporting the outcome of the assessment. In this step, therefore, it is necessary to produce the required information according to the needs of the recipients of the evaluation, and to write and deliver the final results report (see Figure III. 8).

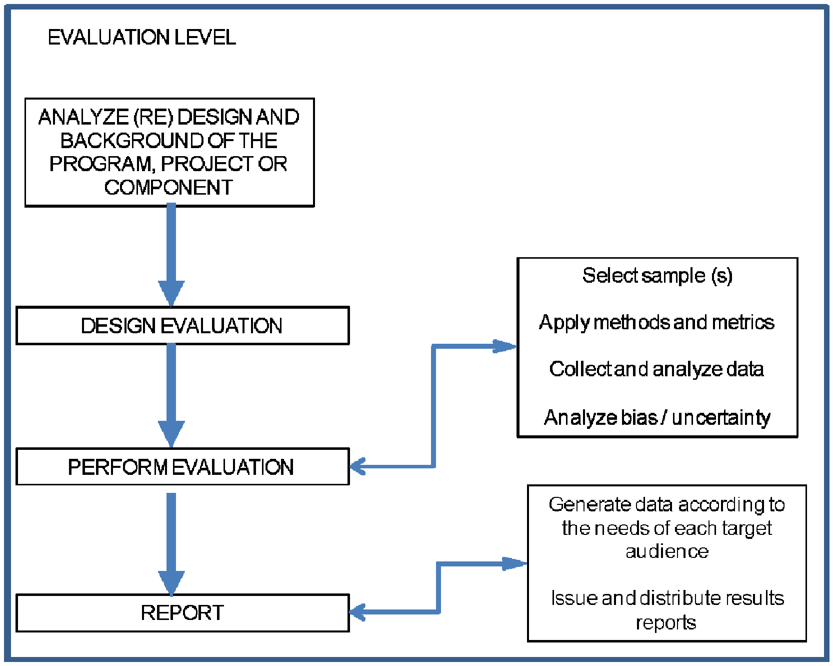

Figure III. 8. Steps 3 y 4: Performing the program evaluation and reporting its results

1.5.3 Results of the application of the methodology to the Chilean case.

The proposed methodology was applied to 12 EE programs implemented during 2011 and 2012 by the AChEE in Industry and Mining, Transport, Commercial, Public and Residential, Education and Training, and Measurement and Verification sectors. Since the AChEE has already measured the direct impact evaluations of these programs through the IPMVP methodology, the application of the proposed methodology focused on the evaluation of indirect impacts, based on the three axes already defined. Thus, the evaluation of the considered programs focuses on determining the level of *Presence*, *Valuation* and *Mobilizing capacity* within each interest group (IG) defined as relevant for the assessment. In doing this evaluation, we designed structured and semi-structured interviews, surveys, and focus groups, and we applied them to representative samples of each IG defined as relevant in order to measure the indirect impacts. Table 1 presents an example of the application of these instruments, just to get an idea of the evaluation design.

When reporting the results, we classified the answers to each question asked during the evaluation in three ranges, according to the degree of indirect impact achieved. Specifically if obtained answers, on average, reached a favorable outcome in a range between 0% and 40%, we define the achieved indirect impact in the assessed axis as LOW; if they were greater than 40% and less than 70%, we define the achieved indirect impact as MEDIUM, if they were between 70% and 100%, we consider the indirect impact as HIGH.

Table 1. Example of the design of an evaluation, regarding aspects to evaluate and data collection methods

Program	Aspects to evaluate	Data collection methods	Objective of the evaluation and questions to ask in order to attain it
Energy Audits	Actions taken as a result of participating in the program to improve the efficient use of energy, such as changing lighting system or equipment	Interviews to a group of program participants	Purpose of the evaluation: Determine the number and type of actions taken as a result of the program. Example questions used to collect information: Did you make changes to the lighting system or to some equipment? How many lights did you change? How many pieces of electrical equipment did you change?
	Level of increased awareness of the potential for energy improvement	Survey (questionnaire) applied in order to measure differences (before and after the program) among the participants. Analysis of the reports of the energy audit.	Purpose of the evaluation: Determine the variation in the knowledge of the people exposed to the program Example questions used to collect information: What is your potential energy savings? What percentage of your costs would you save if you took measures to reach these potentials?

Four large programs in the Industry and Mining Sector (Encouragement for energy management systems based on ISO 50001; Encouragement for the diagnostics and implementation of EE projects; Pre-feasibility of investments in EE in the industry; and dissemination, training and implementation of cogeneration projects) were evaluated. In order to clearly explain the application of the proposed methodology, a detailed description of the application of the methodology to one particular program is presented. Accordingly, next it is described the results of applying the assessment methodology to the pilot program encouraging the incorporation of ISO 50001.

Step 1. Analyze the design and background of the program "encouragement for energy management systems based on ISO 50001"

This program started in 2011 and it was still under execution at the time the evaluation was performed. The overall objective of the program is to build human capacity to incorporate energy management systems (EMSs) and to promote their use. The program is defined as a pilot program aimed to examine the acceptance level of the introduction of EMSs in the industry.

This program has two components, which can be implemented either by the same company who applies for the ISO50001 standard or by a consulting company. The first one is the implementation and certification of the standard and the second one is the dissemination of the ISO50001 standard and the associate results within the industry and mining sector. From June 2011 to March 2012, the program was born as a *pilot implementation*. The first certification was awarded in 2012. Interestingly, most of the companies awarded in 2012 with the ISO50001 also participated in other EE programs such as audit and pre-feasibility programs. Regarding the dissemination of the ISO50001 standard, seminars and conferences were held at the main regions of Chile during 2011 and 2012.

The theoretical model underlying the design of the program is based on the goal of generating the necessary human capacity within companies so that they can incorporate and maintain an EMS based on ISO 50001, which allows a more efficient energy use in the long term. This program, in particular, did not have a preliminary design of the program impact evaluation.

Step 2. Designing the program evaluation plan

The main objective of the evaluation is to measure the indirect impacts of the program, considering both companies that are already awarded the ISO50001 standard and those companies that are within the process of being certified. Additionally, another goal of the evaluation is to estimate the potential for replicability of these pilot implementations, by measuring the intentions the people attending some specific seminars declared. Three IG were defined for the evaluation, depending on the program's and evaluation's objectives, and the type of information required. These three IG are: participating companies that had already been certified ISO50001, companies that, at the time of the assessment, were still in the process of implementation of an EMS, and the participants of the seminars organized by the AChEE during 2011 to promote this program. For the first two IG, in-depth interviews were conducted to the main managers involved in the project. For the third IG, surveys were conducted to a sample of people who attended the ISO50001 seminars organized by the AChEE in several regions of Chile. In this last case, an unbiased random sampling was performed so that more than 10% of the sample universe was covered.

In each one of the three IG, indirect impacts were measured through the presence, valuation and mobilizing capacity of the program. Some examples of the questions asked during the interviews were: How many people in your company know the EMS based on ISO 50001? Have you released outside the company the results of the pilot experiment conducted in your company? What do you think is the most valuable outcome of implementing the ISO 50001 in your company? On a scale of 1 to 5, where 5 is the highest rating answer: How useful was implementing ISO 50001 for your company? How easy was implementing it in your company? How much do you agree with the following statement: "Using the EMS based on ISO 50001 in your company, you can get a significant level of energy savings"?

Step 3. Perform the evaluation of the program

The collection of information among different IG was performed accordingly with the roles, tasks and calendar set. The data collected from the interviews and surveys were analyzed and the results were presented in a report (summarized below).

Step 4. Report of Evaluation Results

Conclusions of the evaluation program for IG 1: Certified companies.

Regarding the presence axis, the results of the assessment show that the EMS has a large penetration and intensity among the employees of the certified company. This high level of presence was expected because of the regulatory requirements of ISO 50001 and, mainly, because of the advertisement of the certification that the company itself makes within its employees.

A medium level is reached in the evaluation dimension of the valuation axis. This is a consequence of the large amount of information required in the certification process and the lack of adequate training to promote the installation of permanent human capacity within the organization for the EMS maintenance over time.

Since several specific EE actions have been taken after the company got certified, the mobilizing capacity axis reports a high level of success of the program, in both the transcendence and the movement dimension.

Conclusions of the evaluation program for IG 2: Participating companies that are in the certification process

Regarding the presence axis, the results of the assessment show that the EMS has a large penetration and intensity among the employees of the certified company. This high level of presence was a little surprising since it might be expected that companies advertise the ISO500001 certification only after getting the certification, and not before. However, results show that, at least during the first years of implementation, companies do advertise the ISO50001 standards immediately starting the certification process.

A medium level is reached in the evaluation dimension of the valuation axis. This is due to the good perception of the value associated to the certification on one hand, and the difficulties of getting the information needed to implement the EMS, on the other hand.

The mobilizing capacity axis reports a high level of success of the program, in both the transcendence and the movement dimension, since several specific EE actions have been taken since the company started the certification process.

As Pardo pointed out [77], we verify that the strategies to improve technology in the industrial sector should be accompanied by training programs on labor standards of EE through EMSs.

Conclusions of the evaluation program for IG 3: Seminar participants

Regarding the presence axis, the results of the assessment show a medium level of success of the program. This is mainly because the seminar attendees do not relate the dissemination of EMSs under ISO 50001 with a program of the AChEE designed to provide technical support for companies wishing to implement these EMSs.

A medium level is reached in the evaluation dimension of the valuation axis, because of the broad spectrum of tasks performed by the seminar attendees.

The mobilizing capacity axis reports a high level of success of the program, in both the transcendence and the movement dimension. However, in this case, several specific EE actions have been taken by the seminar attendees after attending the seminar, but at a domestic level (and not necessarily related with the company where the attendees work).

Evaluation of other programs on industry and mining sector.

In addition to the encouragement for energy management systems based on ISO 50001, other three programs in the Industry and Mining Sector: Encouragement for the diagnostics and implementation of EE projects; Pre-feasibility of investments in EE in the industry; and dissemination, training and implementation of cogeneration projects were evaluated. The results are summarized in Table 2.

Regarding the encouragement for the diagnostics and implementation of EE projects, the overall objective of the program is to encourage companies to develop energy audits, as a key aspect to the identification of EE opportunities.

Regarding the pre-feasibility of investments in EE in the industry, the overall objective of the program is to encourage the development of economic pre-feasibility studies prior to the realization of EE project investments in the industry.

Regarding the dissemination, training and implementation of cogeneration projects, the overall objective of the program is to plan and prepare cogeneration projects and build national human capacities for the development of such technologies. This program is defined as a pilot program aimed to examine the acceptance level to this type of actions from the industry.

After performing all these evaluations in the industry and mining sector, we verify that, as pointed out Alvial et al., [78], to promote the success in the EE programs, it is necessary to have a multidimensional view. Considering cultural, symbolic, affective and discursive aspects of the agents involved in the system intervened.

Table 2. Summary of indirect impact evaluation of programs in the industry and mining sectors

Program	IG	Presence	Valuation	Mobilizing capacity
Encouragement for energy management systems based on ISO 50001	Participating companies certified	HIGH	MEDIUM	HIGH
	Participating companies in process to certificate	HIGH	MEDIUM	HIGH
	Seminar participants	MEDIUM	MEDIUM	HIGH
Encouragement for the diagnostics and implementation of EE projects	Companies that conducted energy audits	LOW	HIGH	N/A
Pre-feasibility of investment in EE in the industry	Participating companies	N/A	LOW	HIGH
Dissemination, training and implementation of cogeneration projects	Participating companies	N/A	MEDIUM	LOW

Results obtained in the evaluation of programs in the transportation sector

The indirect impacts of three programs in the transportation sector were evaluated; results are summarized in Table 3.

Regarding the incentive to the introduction of EE management tools in nationwide freight transportation, the overall objective of the program is to create an EE culture in freight transportation companies. The beneficiary companies of this program and the associated employees were defined as IG for the evaluation.

Regarding the encouragement of improved energy management standards in public transportation companies in Santiago city, the short-term program objective is encouraging the adoption of good practices in the efficient consumption of fuel in public transportation of passengers by developing pilot experiences. However, this program has also a long-term goal, which is the adoption and replication of EE actions in the rest of the public-transportation industry. The beneficiary firms and some non-beneficiary companies of the same sector were defined as IG for evaluation.

Regarding the promotion of efficient driving, the program objective is encouraging the adoption of efficient driving concepts in drivers of road freight vehicles and, in this way, increasing the vehicle performance in the long term. To achieve this goal, the AChEE developed a website (www.conduccioneficiente.cl), which contains multimedia concepts and materials with efficient driving tips depending on the type of vehicle that is driven. Frequent drivers who are users of the website were defined as the IG. In this case, the presence, valuation and mobilizing capacity axes for both the efficient driving program and the use of the website designed for this purpose were measured.

Table 3. Summary of indirect impact evaluation of programs in the transportation sector

Programs	IG	Presence	Valuation	Mobilizing capacity
Incentive to the introduction of management tools in EE in freight transportation	Beneficiary companies	N/A	HIGH	HIGH
	Employees of beneficiary companies	MEDIUM	MEDIUM	MEDIUM
Encouragement of improved standards of energy management in public transportation companies in Santiago city	Beneficiary companies	N/A	LOW	LOW
	Not Beneficiary companies	LOW	HIGH	HIGH
Promotion of efficient driving	Frequent drivers / concept of efficient driving	MEDIUM	HIGH	HIGH
	Frequent drivers / usability perceived of the website	MEDIUM	HIGH	HIGH

Results obtained in the evaluation of programs in commercial, public and residential sector

The indirect impacts of two programs in the commercial, public and residential sector were evaluated. The results are summarized in Table 4.

Regarding the refurbishing of public buildings, the program objective is to promote the implementation of EE measures that contribute to reduce energy consumption in buildings of the public sector, maintaining or improving the level of comfort of the occupants of the building. The program also seeks to validate business models where the generated savings allow financing the investments. Program managers in the beneficiary institutions were defined as the IG.

And regarding the creation of the manager profile in EE and design of the training plan, the program objective is to create an EE manager profile that enables the implementation and maintenance of an EMS of the activities performed by those people involved on the EMS. The IG was defined as individuals trained through this initiative.

Table 4. Summary of indirect impact evaluation of programs in commercial, public and residential sector

Program	IG	Presence	Valuation	Mobilizing capacity
Refurbishing of public buildings	Program managers	N/A	HIGH	HIGH
Creation of the manager profile in EE and design of the training plan	Individuals trained	N/A	HIGH	HIGH

Results of the evaluation of programs in the education and training sector

The indirect impacts of two programs in the education and training sector were evaluated. The results are summarized in Table 5.

Regarding the incorporation of EE in schools and society, the program objective is to build capabilities in various stakeholders of the educational community (educators, students, staff and parents) for the incorporation of EE actions, starting from pre-school. The program seeks for the implementation of educational programs that are relevant for each actor and level, creating educational resources (material) for the use in the classroom, in the school and at home. Each of the groups of the stakeholders of the educational community corresponds to an IG for the evaluation.

Regarding the research, development and innovation, the program objective is to develop specialized human capital in EE, strengthening the technical and professional capabilities at local level, improving the educational offer at university level and generating knowledge about applied research. We define two IG: the project´s managers in the targeted universities and the representatives of the companies participating in the EE programs, in association with a university.

Table 5. Summary of indirect impact evaluation of programs in education and training sector

Program	IG	Presence	Valuation	Mobilizing capacity
Incorporation of EE in schools and society	Preschool educators	N/A	HIGH	HIGH
	Preschool students	N/A	MEDIUM	N/A
	Preschool staff	HIGH	HIGH	HIGH
	Preschool Parents	MEDIUM	HIGH	N/A
	School educators	N/A	HIGH	HIGH
	School students	N/A	LOW	N/A
	School staff	HIGH	HIGH	HIGH
	School Parents	MEDIUM	MEDIUM	N/A

Research, development and innovation	Project's managers	N/A	HIGH	HIGH
	Project's related companies	LOW	HIGH	N/A

Results of the evaluation of programs in the measurement and verification sector

In the measurement and verification sector, we only evaluate the indirect impacts of one program: the web platform for registering the electricity consumption in the public sector. The overall objective of this program is to support the monitoring of the energy consumption in public institutions. The users responsible for updating the web platform created for this purpose were defined as the IG. The results are summarized in Table 6.

Table 6. Summary of indirect impact evaluation of programs in the measurement and verification sector

Program	**IG**	**Presence**	**Valuation**	**Mobilizing capacity**
Web platform for registering the electricity consumption in the public sector	Users responsible for updating platform	LOW	HIGH	HIGH

1.5.4 General discussion

As it can be observed from the results presented, most of the programs implemented by the ACHEE have medium or high rating on both the valuation axis and the mobilizing capacity axis, among the different IG considered. However, the presence axis is evaluated at a low level in most cases, which means the EE programs and their subjects are poorly known. This result suggests there is a serious weakness in the programs and their implementations, especially when considering that cultural changes are needed to achieve large levels of EE outcomes and to promote the internalization and long-term positioning of the EE concept. Accordingly, the results suggest that, in order to truly generate market transformations, it is first required to inform and educate people on the need for a more efficient use of energy.

By applying the proposed methodology, in addition to evaluate the indirect impacts of the EE programs, we detected the presence of some key variables that significantly influence the programs' outcomes. Among these variables, we highlight the recognition of specific profiles of the sectors and population to be targeted by the programs and their cultural, social, economic and educational features. The existence of these variables suggests that the design of EE programs and the definition of their theoretical frameworks must be very carefully analyzed, incorporating these variables and their potential impacts on the results. In this sense, as pointed out by Pelenur [79], the effectiveness of EE programs can be improved through an interdisciplinary approach to the problem.

It is worth to remark, once again, that the effectiveness of an EE program cannot be only measured by the energy saved for every dollar invested (i.e., the direct impacts) because there are other effects that are very important too. In the past, measuring only the direct impact of programs has led to an overvaluation of programs oriented to equipment replacement. However, investing in EE programs that also have indirect effects is necessary for reaching a long-term market transformation. Such programs, with indirect impacts, create a platform for long-term success of programs with direct impact. Because, on one hand they cannot be assigned to a particular program and, on the other hand, they facilitate the incorporation of EE actions without a permanent economic incentive (subsidy) by governments. As pointed out by Blumstein [8], investing in programs with direct impact and investing in those programs with indirect impact are complementary strategies.

Finally, a summary of the aggregate results of the overall evaluation performed is shown in Figure III.9. These results were obtained on the basis of the requirements for each program-IG group, and for each axis of indirect impact levels.

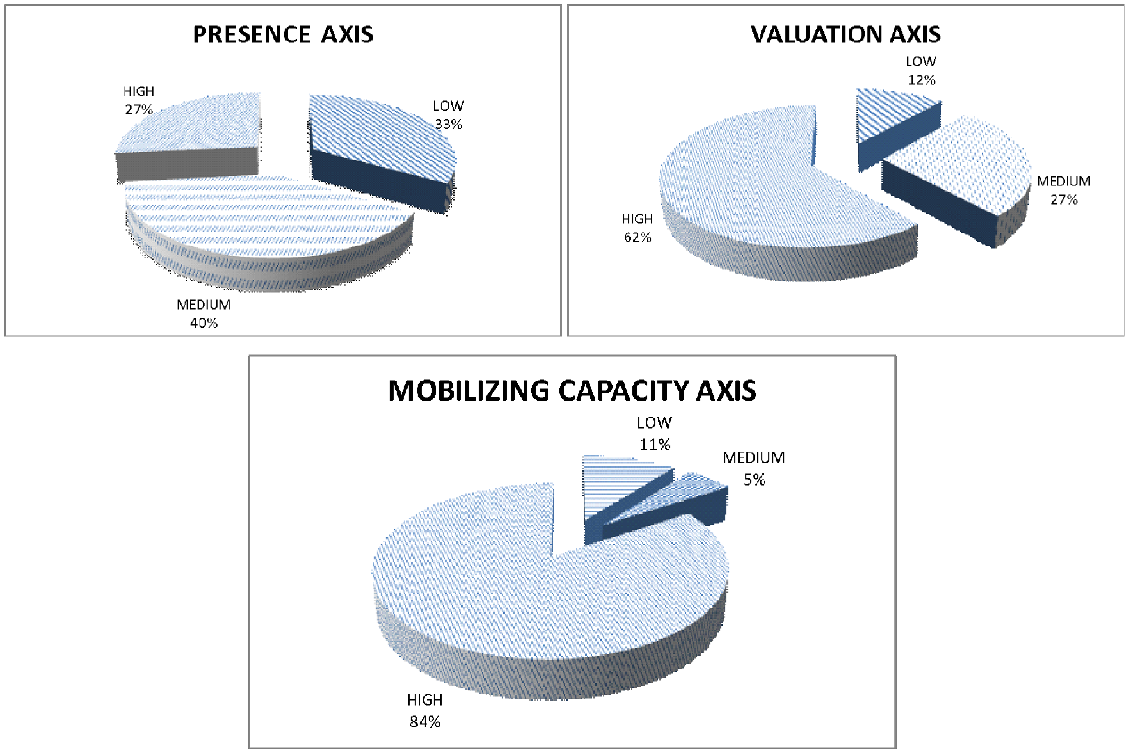

Figure III.9. Aggregate results of the indirect impact evaluation of the AChEE's programs

1.6 Symmetric TOU in SIC

Currently, an ongoing debate is underway in many countries regarding the sources of energy, their generation and use. The sustained increase in global demand for electricity, its direct relationship with countries' economic development, the cost of generating and the impact on the environment that power generation produces, have shown the need to take actions that allow to optimize its use. There are various measures that can be implemented to achieve this goal, some of which are intended to influence the behavior of the end users of electricity, and that could be channeled through the electricity distribution industry. In this way, the debate at the global level has also focused on the design of regulatory mechanisms that encourage distribution companies (DISCOs) to implement energy efficiency (EE) programs. This because, they do not have economic incentives to incorporate EE programs to help their consumers to be more efficient in the use of energy if the programs translate into a decrease in sales and income.

Today, the majority of residential consumers of electricity in developing countries are offered a service with a flat tariff scheme, based on the average cost of providing the service. This system does not provide such customers with incentives to modify their pattern of consumption in periods when the cost of producing the electricity rises [80,81]. Thus, demand responsiveness to the information on prices, a critical variable to the proper functioning of markets, is not present in the majority of these energy markets. In contrast, a flexible pricing mechanism is capable of generating such a decrease in the variability of consumption levels among hourly segments during the day, which in turn reduces uncertainty and variability of electricity costs [82]. Thus, flexible pricing offers opportunities to reduce the electricity supply costs and the risk of not satisfying the demand for electricity. In this way, the design of a suitable system of flexible tariff can help to operate a smart grid [83].

Flexible pricing has been implemented generally for large consumers (commercial and industrial). A good example of this is the Georgia Power program, in which more than 1,600 of these large consumers face different hourly rates and where close to 850 MW in power demand reduction have been verified [84]. In the case of Chile, Mendez [85] points out the importance of having an efficient pricing system of electrical energy for users in order to send the right signals to the market to make the expansion of transmission lines and the construction of new power generation more efficient within a competitive market.

Generally, TOU systems are designed to minimize total system cost, which may cause losses in DISCOs, generating opposition. On the contrary, the present paper proposes a TOU system for electricity consumption in Chile where optimal prices are obtained in order to maximize total income of DISCOs. In this manner, the proposed TOU system is, by definition, beneficial for DISCOs and it may lead to a win-win situation among DISCOs and consumers.

This work investigates the results of the design of a flexible pricing system (of the Time of Use, TOU, type) for electricity consumption in Chile, where an optimal pricing model for electricity consumption has been determined by means of price-consumption elasticity, in such way that, for each simulated scenario of the response of users associated with such node, there is an indicator that shows the price-consumption sensitivity in each price scheme. Thus, we measured the effect of the application of a flexible pricing system (of the TOU type), with optimal prices defined using the elasticities, which would induce the desired behavior in the end consumer of electricity in a way that the consumption and electricity prices can reflect more closely the risk associated with the power generation cost achieving greater efficiency of the electrical system without affecting the profit earned by the DISCOs. We model the response of the demand and the DISCOs' objective following this rationale.

1.6.1 "Time Of Use" (TOU) Pricing System

There are several systems of electricity pricing in the world. Some are fixed, where there is a flat fee regardless of the load curve and the time of consumption (which corresponds to the current Chilean model for residential customers), and some are flexible, whose rate is differentiated on a temporal basis [86]. Within these latter ones, are included the Time of Use (TOU) Pricing, Critical Peak Pricing (CPP), and Real-Time Pricing (RTP), which have been detailed by several authors [87-90].

In the specific case of TOU system, both prices and periods of application are known a priori and fixed to some length, typically a season [91]. However, and although the TOU system has different rates for each defined block, these rates do not consider the times of saturation or demand peak of the system and do not capture variations in demand and costs of operation in real time. i.e., uses just one price for the same periods of time, regardless the status of load on the system or wholesale prices. However in order to reflect seasonal variations, a readjustment of prices and/or the duration of the blocks is performed two or three times a year. Faruqui and Malko [92] presented the results of twenty experiences of TOU systems allowing conclude that:

1. TOU pricing system reduces the consumption in peak periods, however in average or low consumption periods it remains constant or increases in small quantities.
2. A change in the load curve is rarely observed and the TOU system prices cause an overall decrease in the daily consumption.
3. Users who demand power in on-peak periods are more price sensitive than those who do so in off-peak periods.
4. Elasticities for on-peak and off-peak periods vary in a range of 0 to - 0.4. These differences in the variations are explained by the various climates, prices and consumption used for the study.

On the other hand, if implementation of the TOU system considered the voluntary association of customers to the program, a problem could arise in the achievement of the improvement objectives of the proposed EE measures, as in this case only those customers who obtain savings related to an overall decrease in consumption or generate one block tariff to another transfer would subscribe to this pricing scheme. This situation may generate a loss of income for the DISCOs due to lower sales associated with consumers who subscribed to the plan; and in that context, these companies will seek to remedy such loss increasing the rates of those consumers not hosting the program, thus determining a zero sum game insofar as the savings achieved in the global system [92].

Therefore, to address the problem of flexible electricity consumption pricing, there should be a consideration of the impacts on two important variables: the revenue earned by electric power distribution companies and the response or variation in consumption response of users to the new pricing of electricity. To combine both effects may generate a win-win strategy, benefiting both companies and end-users.

1.6.2 Model of flexible pricing TOU type adapted to the Chilean case.

Background information.

The proposed flexible pricing model is applied to the main Chilean electric system, SIC, which covers the majority of the energy consumption of the country. In Chile, energy and power prices for large consumers (with a level of consumption over 2,000 kW) are determined by bilateral agreements between parts. However, in the case of energy supply to end- users whose connected power is less than or equal to 2,000 kW, the price is established by law regulation. Thus, customers that make up this market segment are called regulated customers.

For regulated customers, the Chilean electricity law distinguishes prices at generation, transmission, and distribution levels. The latter prices are determined as a value added per concept of distribution operations and a charge for using the grid. The generating companies can sell their energy and power both in the large consumer market, where the price of the transaction is agreed freely; and also, in the market of the DISCOs, where the price is regulated based on a "nodal pricing". The price that the DISCOs can charge to regulated customers located in their area of distribution, for the distribution of electricity service, is given by the following expression:

$$P_f = P_n + TCG + AVD \tag{1}$$

where:

- P_f : End-user price
- P_n : Regulated nodal price
- TCG : Toll charge for grid use
- AVD : Added value of distribution

While nodal prices are commonly set by market competition, in Chile they are regulated by law. Accordingly, Chilean "nodal prices" are set twice a year, in the months of April and October of each year. These regulated nodal prices have two components: the first, called basic price of energy, which corresponds to the average time of the marginal costs of energy from the electric system, operating at the minimum updated cost of operation and rationing, during the period of study; and the second, called the basic price of the peak power, which corresponds to the annual marginal cost of increasing the installed capacity of the electrical system considering the cheaper generating units, determined to provide additional power during the electrical system's peak demand hours of the year, increased by a percentage equal to the theoretical power reserve margin of the electrical system.

For each one of the nodes of the electrical system, energy and power-related penalty factors are calculated, that multiplied by the respective basic price of energy and peak power determines the price of energy and power in the respective node. On the other hand, the Added Value of Distribution, AVD, is set every four years by the Ministry of Economy, Development and Reconstruction, and corresponds to an average cost that includes all the investment and operation costs of a theoretically efficient business enterprise operating model in the country, with an efficient investment policy and management. However the AVD does not necessarily recognize the costs actually incurred by the DISCOs.

Thus, rates that finally face regulated distributors clients consist of prices of generation, transmission, and added values by distribution costs. Generation prices correspond to the regulated nodal prices determined semi-annually; prices of transmission component corresponds to the toll for the use of backbone transmission facilities; and finally the component distribution, corresponding to the AVD, which represents the payment to the company distributor of their cost of investment, operation and maintenance, losses, and expenses of administration, billing and customer care.

Model assumptions.

The flexible pricing model to be proposed seeks to implement a rating system, where the residential end-users of energy (regulated clients, in the Chilean case), assume a larger cost if their main daytime energy consumption takes place in slots of congestion or larger aggregate consumption of the system. Thus, economic incentives are generated for users to reduce or "move" consumption in congestion (on-peak demand) sections to stretch medium or low level consumption, making them sensitive to higher costs of generation, transmission and distribution in on-peak schedule.

Mathematically, and as an assumption for the tractability of this model, the SIC's system of nodes complies with the properties of set covering and set packing, by which all tariff solutions comply with the condition of set partitioning and therefore, the optimal rate of the system will be the sum of the best of the partition. Given this configuration, the model will work in a first phase on the basis of a particular node, to later generalize the analysis to the rest of the selected nodes and to the whole SIC system.

To analyze the income received by the DISCOs and the variation in the form and schedules of customer's consumption, there will be a comparison of these variables between the current scenario and the scenario with the proposed scheme. The model will consider the implementation of a flexible hourly charging system comprised by three daily tariff segments (on peak, middle peak and off peak), characteristic of each node. Thus, for each of the nodes that make up the SIC, analysis of their profile of time consumption and the marginal costs of generation associated with that profile will be carried out. On the other hand, as a measure of sensitivity of customers' consumption is not available to variations in the price of electricity, to simulate their response to changes in pricing, we generate different scenarios representing the variation of customers' consumption.

Therefore, each scenario will be a simulation of a possible "turnover" of consumption between each time segment. Thus a study of the current pattern of customer consumption response will be possible for each schedule section, with its corresponding duration and price, in the face of variations in pricing of energy. This model assumes that each node of the SIC reflects the consumption characteristic of the zone in which is located, so that the behavior and consumption of each node may give an account of the behavior of customer consumption in that geographical area. In addition, in this comparative analysis both competing charging periods schemes will be compared during October-April period of each year of study, in order to, not only realize the effect of daily and hourly variations in consumption in certain segments, but also of those variations that are a product of seasonality.

Assuming that eventually there may be energy transfers among different nodes of the SIC, there applies the idea of risk polling[6], which, for the purposes of this model, is considered marginal to the distorting effect of possible transfers of energy on the pattern of overall consumption of the system's clients. However, the variations in price of each segment will be determined, as a measure of sensitivity, establishing a role of consumption-cost elasticity characteristic of each node, so that, for each user's response to prices scenarios differentiated by segments, there will be an indicator to show sensitivity in each consumption-cost associated to a schedule section. It should be noted that for each simulated scenario, there is a characteristic consumption per node, which directly determines the role of elasticity price-consumption in the specific time segment. This function is therefore built by comparing the consumption of each node in each fare segment, with the price level of electricity in this segment.

The model.

The model used in this study can be described as a methodology of seven steps, each of which was applied to all nodes in the main Chilean interconnected power system, SIC. Each of these steps is detailed below. In order to illustrate the implementation over the

[6] Risk pooling is an important concept in the management of the supply chain, which suggests that the variability of demand is low considering the aggregate demand, because the aggregation occurs in different locations. Thus, by introducing inter-decadal with different backgrounds, the effect on aggregate demand is minimized. For further reference see [93].

nodes of the specific step that is been detailed, we use a prototype node (called *Pan de Azucar*). This is made only to explicit the description of the methodological procedure. Figure III.10 shows a schematic picture of the whole methodology used here.

Step1: Obtaining and validating data

For each node belonging to the main Chilean interconnected power system (from now onwards SIC), data regarding both consumption characteristics of each bar and the marginal generation costs associated with that consumption pattern were collected for the years 2005, 2006 and 2007. The information was obtained from the Center for Economic Load Dispatch of the SIC, CDEC-SIC, and from the Chilean National Energy Commission, CNE [94-97].

The information collected was inspected and validated, because in some cases exhibited abnormalities (e.g., negative consumption values), which were excluded from the database.

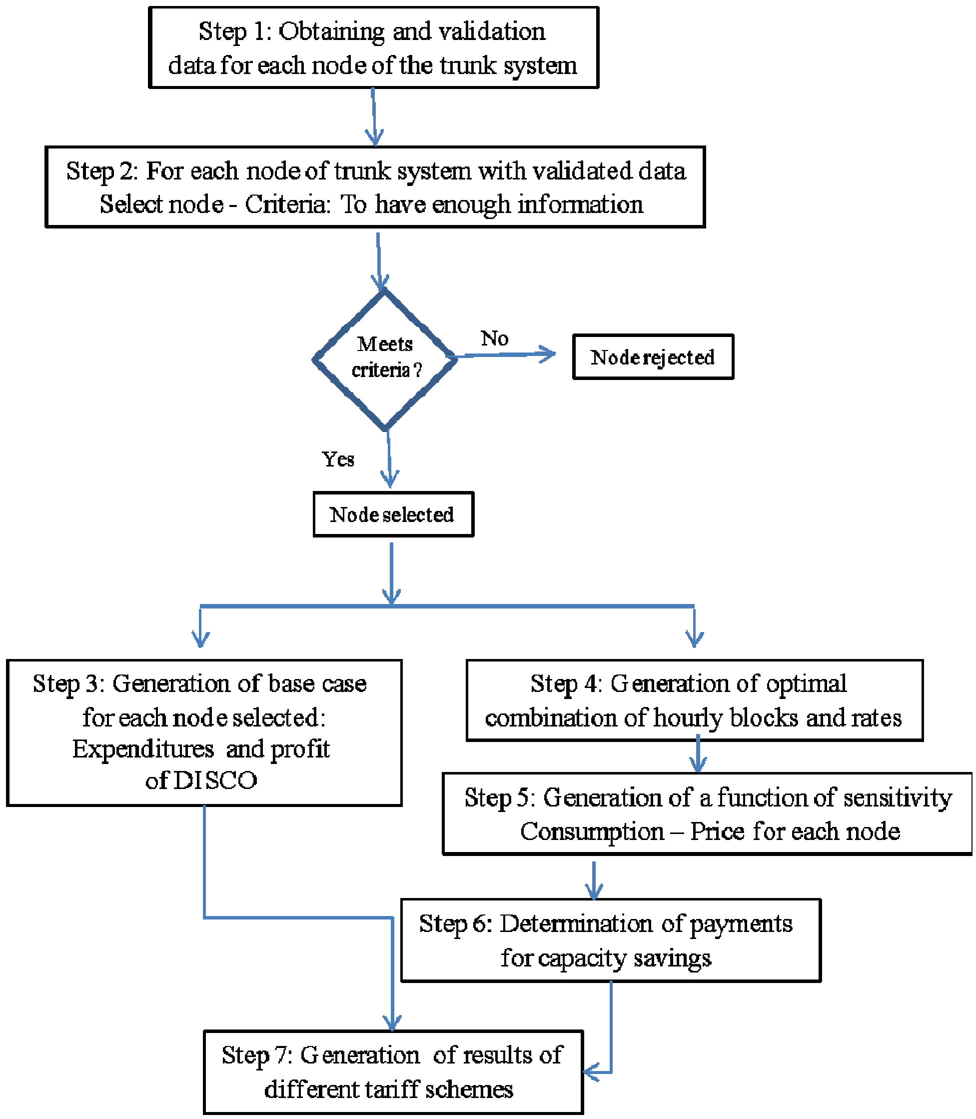

Figure III.10: Methodology of the model

Step 2: Selecting Nodes

Once validated information was available, we selected those nodes of the SIC that had enough information about marginal costs and consumption characteristics of the bars associated to such nodes. Specifically, the criteria for selection of these nodes were two: (i) that they belong to the backbone of the SIC (main nodes), and (ii) that the node has available information regarding the extent of consumption and the marginal costs of the energy in each tariff segment (the latter being needed to quantify the income variation of the DISCOs as a result of the application of the model). To analyze the system, 22 representative nodes of the SIC were chosen. The 22 nodes selected are: Quillota, Carrera Pinto, Valdivia, Los Vilos, Itahue, Rancagua, Huasco, Polpaico, Las Vegas, Paine, Puerto Montt, Punta cortes, Cardones, Pan de Azúcar, Charrua, Rapel, Chillan, San Fernando, Cholguan, San Vicente, Concepcion, and Temuco.

Figure III.11 and Figure III.12 show the daily average marginal costs and energy consumption during the years 2005-2007, for the Pan de Azúcar node (prototype node). These figures reveal the existence of low, medium and high levels of power consumption and marginal cost throughout the day, suggesting the use of a flexible pricing to generate a more bounded behavior of electricity demand for certain critical costs and consumption segments.

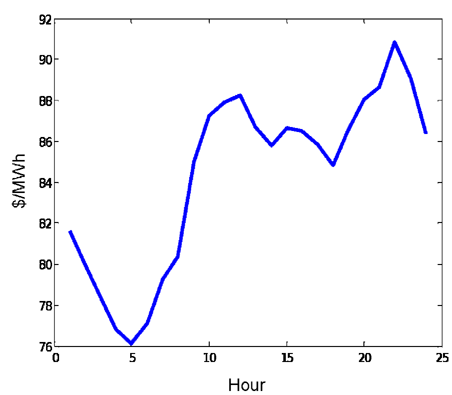

Figure III.11: Daily Average Marginal Costs of the Prototype Node

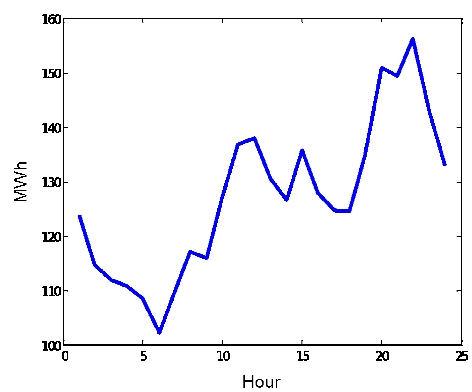

Figure III.12: Prototype Node Characteristic Average Consumption

Step 3: Generation of base case

For each of the 22 selected nodes, the payment of the DISCOs to the generation firms (expenditures) and the profits of the DISCOs were determined in the base case, corresponding to the current pricing system (fixed-tariff system), during the analysis period, 2005-2007. This step has the next sub parts:

i. Payment of the DISCOs to the generation firms in the base case.
ii. Determination of profits of the DISCOs for the base case.

Step 4: Generation of an optimal combination of hourly blocks and rates per node.

To establish a three-segment flexible pricing system, we sought the optimal combination of time segments for each selected node. The desired goal was to maximize the revenue of DISCOs, given the characteristic behaviors of each bar consumption, the cost-based power rating existing in Chile, and subject to the constraint that each time segment has a minimum duration of three hours. The revenue of the DISCO was computed by multiplying the characteristic consumption and the rate for each tariff block. Accordingly, it is necessary to establish, for each node, the optimal duration and the rates for each tariff block. This step has the next sub parts:

i. Rates for each tariff block
ii. Duration of segments of each tariff block

Step 5: Generation of a function of sensitivity Consumption – Price for each node

For each node and optimal tariff segment, a consumption-price sensitivity function was generated, as a proxy to the sensitivity of the consumption of the respective bar, with respect to changes in prices generated from transfers (to be simulated in this model) among blocks with different tariffs. The idea is to obtain bounds on the effects that could be set on consumption in each simulation of energy transfers among tariff blocks and, therefore, determine the energy savings and the effect on revenue of DISCOs.

This sensitivity function was generated from the analysis of daily consumption during the years 2005 to 2007, ranked by every consumption segment (Off Peak, Middle Peak and On Peak), using the least squares method to establish a linear relationship between price and consumption for the seasonal periods included in the horizon. This yields an index of consumption-price sensitivity for each of the time segments (Off Peak, Middle Peak and On Peak) for the period from October to April and for the period from April to October (A total of six values for each one of the 22 nodes).

Step 6: Determination of payment for power savings

For each node under analysis, it is necessary to compare the changes in the revenue of the DISCO produced by potential savings to be gained by the decline of investment in generation capacity, due to the change in the customers pattern of consumption, so as to evaluate if the whole system is more efficient from the energy point of view when reducing the variability of daily consumption. To achieve this comparison, it is necessary to create a proxy indicator to account for the payments for capacity and energy, which DISCOs pay for to the generators, as a way to estimate the savings associated to the peak demand reductions. This proxy indicator will be built as the average value of capacity payments in the study period so that, for every MW decreased during the peak working hours, there is a proportional payment to this drop in consumption. To be able to quantify the potential savings for the system, as a result of decreases in consumption at peak times, reference capacity payments in the Chilean SIC market were considered, contained in the October 2007 nodal price report [26]. In addition, a vector of capacity payments was obtained corresponding to the periods October 2004 to April 2007, which was weighted by the savings simulated between hourly tariff segments of the node in analysis. Therefore, for each simulated variation of consumption between hourly slots, there will be a characteristic capacity savings value.

To quantify the simulated power savings in this exercise, a scenario of change for each node is defined. This scenario is characterized by inducing percentage variations in the behavior of consumers, from increased consumption to lower consumption segments, successively. The idea behind this scenarios' structuring is to account for users' different sensitivities depending on the season in analysis. Users are less sensitive (in their behavior) to price in the April-October period than in the October-April period, because of the winter cold and the lesser amount of light in this day period. Thus, for instance, for the prototype node, we simulate a scenario where there is a 10% transfer in the nodal consumption from on-peak segment to middle-peak segment and a 10% transfer from middle-peak segment to off-peak segment, as a result of the implementation of the new tariff.

Step 7: Generation of results of different tariff schemes

With the information generated in the above steps, for each selected node, it was determined: the payments that consumers make to DISCOs under the flexible pricing scheme, the payments that DISCOs make to generators for the energy provided, the profits of DISCO in both the base case and in the case of flexible pricing and the spread between the two systems, considering also the savings in power capacity.

1.6.3 Results obtained in the prototype node

The overall results for the prototype node, where different charging mechanisms are compared through the access of the distributors, are shown in Table 7.

Table 7: Comparison of utilities with flexible pricing model and profit under current model for prototype node: 2005-2007 period. (Asymmetric case)

	Results for the prototype node	Millions of $
A	**Payment made by consumers to the distributors, under the flexible pricing scheme** (Price tariff blocks*Consumption in blocks)	365.66
B	**Payment of the distributors to the generators** (Nodal Price* Consumption in blocks)	335.9
C	**Utilities of distributors, under the flexible pricing scheme** (A-B)	29.76
D	**Profit under current model for node model** (AVD* Consumption in blocks)	11.62
E	**Spread** (C-D+ Saving for payment power)	18.67

Table 7 shows that the payment made by consumers to the distributors, under the flexible pricing scheme ($365.66 million), is larger than the payment of the distributors to the generators ($335.9 million). This difference is a proxy for added value distribution plus tolls per use of the backbone transmission system. On the other hand, the utility obtained by DISCOs is superior in the scheme of flexible pricing than in the base case, with a constant energy price, only updated by seasonality (winter & summer rates) factor, thereby creating a positive spread of flexible pricing in relation to charging fixed (current) pricing. The explanation of this behavior lies in the shape of the node's curve and the simulated scenario consumption (10% transfer of energy consumption among on-peak, middle-peak and off-peak hours, respectively). This situation determines that benefits of the pricing scheme vary from node to node.

Now, if the effect of the consumption variability is not only absorbed by the distribution company, but it is also "transferred" to the whole electricity supply chain, this creates a communication link between the final consumers of energy and the generators. In this way, if there are variations in the costs of generation caused by different reasons (such as a possible period of drought, increases in cost of fuels and other inputs of the power generation process chain, or problems of a contractual nature and/or dispatching), it will be quickly reflected in the amount of energy consumed by the regulated customers. There are several ways to convey the sensitivity of consumption, one of them is through the current setting of a fixed nodal price, which collects the variability, but with a lead time or gap of almost 6 months. Another way is the generation of a nodal price which is differentiated by time, similar to the flexible pricing scheme previously mentioned, where different slots with a different price/charge each is faced by end users. A hypothetical situation in which there could be a symmetrical flexible pricing on "both sides of the distribution chain", that is where there is a flexible pricing to consumers to the distributors, and these in turn have a flexible payment scheme based on the latter to the generators, and where each node could be charged differently according to a defined pattern of consumption, would give the following results:

Table 8: Comparison of utilities and profits under flexible pricing model and transmitting the variability of electricity consumption supply chain for node model: 2005-2007 period. (Symmetric case)

	Results for the prototype node	Millions of $
A	**Payment made by consumers to the distributors, under the flexible pricing scheme** (Price tariff blocks)*Consumption in blocks	365.66
B	**Payment of the distributors to the generators, under the flexible pricing scheme** (Gen. Price tariff blocks)*DISCOs use in blocks	329.09
C	**Utilities of distributors with flexible pricing model** (A-B)	36.57
D	**Profit under current model for node model** (AVD* Consumption in blocks)	11.62
E	**Spread** (C-D+ Saving for payment power)	25.48

Table 8 shows an increase of 6.81 millions of dollars between different pricing models for the system, by effect of transmitting the variability of electricity consumption supply chain, considering the 2005-2007 period. This is explained by the typical consumption pattern in the node; reason why, this greater bonanza for effect of flexible pricing that is transferred to the supply chain, can vary from node to node.

Through the generalization of the symmetrical flexible tariff model applied to the Chilean SIC it is possible to obtain, considering initiatives that promote a 5% savings in real consumption during on-peak hours, during both winter and summer, the spread or difference between the proposed and the current systems is of $811,7 millions in the 3-year study period.

1.7 Measures to reduce CO_2 emissions in SIC

The growth of countries is generally related to their ability to provide energy [1-13,98]. However, despite the benefits energy availability brings to the economies, energy generation and use entail some negative externalities, especially in countries where energy production significantly relies on fossil fuels. This leads to greenhouse gas emissions causing climate change and the global warming [3,5,14-18]. This situation, in general, has highlighted the need for countries to move towards sustainable economic growth and thus, to propose and establish measures to decrease their carbon emissions [19-23]. There is not a single solution to face this challenge; so different measures have been conduced worldwide to attempt to solve this problem.

In this line, nowadays we can observe in several countries, an increase of renewable energy to produce electricity [6,24]. These sources, also named non-emitting energy forms [25], include as options: eolian, solar, geothermal, hydro, and bioenergy, among others. The main objectives of these clean sources are decreasing reliance on imported energy, decoupling rising fossil energy use from economic growth and reducing CO_2 emissions [26-28]. Despite this fact, it is possible to note that the use of fossil fuels continues to grow [19].

Governments have proposed some other measures, in addition to renewable energy integration, to reduce CO_2 emissions. Among these measures, we can mention the definition of emissions standards and/or carbon taxes, the introduction of carbon capture technologies and the incorporation of mechanisms promoting energy efficiency (EE), which is understood as the optimization of the energy required to achieve a given level of service. Thus, in this context, EE plays a key role to contribute to achieving these aims [47]. Nonetheless, it is important to note that each of these measures has certain characteristics and implementation constraints, leading to different levels of results and market implications.

1.7.1 Literature review

Some strategies have been proposed and implemented in different countries in order to reduce their GHG emissions, especially in the most-intensive emitters' countries. These strategies include set renewable energy targets, carbon taxes, flexible electric tariffs, emission trading systems and promote EE measures, as efficiency standards for cars and appliances, among others [5,12,23,98].

In this context, an important energy policy has been the promotion of the use of renewable sources to generate electric energy. Nowadays, coal is still the most used resource to generate electricity from thermoelectric power plants. Thus, the power sector is one of the most important contributors to GHG emissions [6,11,15,100.101,102].

For instance, the programs to promote renewable energy development in China have had the reduction of CO_2 emissions as the main objective, jointly with to seek for less reliance on imported energy. These measures aim to decouple the rising fossil energy use from the economic growth over the next several decades, expecting at the same time to achieve a positive impact on local air and water quality [27].

Other way to face this challenge has been the design and implementation of efficient emissions markets. In this context, Dormady [103] and Ellerman et al. [104] have analyzed the effects of command-and-control and tax-based policies on one hand and market-based approaches on the other hand. Recently, the use of auctions for the allocation of tradable emission permits, that are consistent with the polluters-pay principle, has been proposed to avoid inherent problems of centralized allocation [105-111]. In this context, policy makers have become increasingly interested in the use of carbon taxes as a means of reducing greenhouse gases [112]. However, there are still some outstanding issues related to the effectiveness of carbon taxes and its impact on the welfare of Households [113]. Some authors argue that a carbon tax is regressive because it produces an energy price increase that particularly impact to poor people [6,110,114-118]. Other authors point out that carbon taxes have adverse impacts on economy, especially for lost production and international competitiveness [119,120].

Nevertheless, some authors have stated that carbon taxes represent an efficient method to address concerns over coal and energy intensity and that, in the short and medium terms, they reduce CO_2 and non-CO_2 GHG emissions, while encouraging adaptations of existing capital equipment. The basic rationale is that introducing carbon taxes increases consumer prices of coal, electricity, natural gas, among others services, inducing decreases in their final consumption [19,102,121,122]. It should be noted here that, naturally, the rise in energy prices will lead to a significant decrease in consumption only when the price elasticity of demand is larger than one. This may not be the case in all cases. Additionally, carbon taxes and the consequent increase in the price of energy will succeed in replacing certain resources used to generate energy, when these cleaner energy sources and technologies are available at competitive prices. In this sense, Zhang and Baranzinic [122] declared that the carbon tax rate required to achieve an important decrease of GHG emission depend, among other variables, on the autonomous (i.e., non-price-induced) energy efficiency improvement, the possibilities for fuel substitution and the availability of cleaner technologies. So, carbon taxes may have significantly different effects among countries.

In other line of research, some authors have reported the way some countries have worked in the promotion of EE as a measure not only to minimize the influence of energy use on climate change, but also with the objectives of maximizing the local air quality; minimizing the financial risk, the investment costs and the impacts of building new power plants and transmission infrastructures; and maximizing the security of energy supply [5,15,17,24,47-55]. So, in this context, governments around the world have developed policy frameworks to increase the role of EE in meeting new energy demand. For instance, the Japanese government, in the last few decades, has been implementing an energy conservation policy to achieve EE aims, largely motivated because around 1990 global warming emerged as a problem and CO_2 emissions reduction became an important issue. Since then, EE has been one of the most useful methods for achieving the goals of the Kyoto Protocol [54]. As well, the promotion of the efficient use of energy has received a lot of attention in the European Union (EU). This has been an important policy objective of the EU member states since the oil shocks in the 1970s, where energy savings became important in the context of high oil prices, leading to reductions on energy import dependence and GHG emissions [49,51,56].

1.7.2 The model - Background information

The Chilean electric system is composed of 4 subsystems. The two largest systems are the Central Interconnected System (SIC) and the Northern Interconnected System (SING), which covered 99.5% of the total country electric generation in 2013. The SIC is the main system of the country. In 2013, the SIC reached 74.3% of the total country electric generation, while the SING reached 25.2% [123]. The Chilean electric system has been developed in the last years with a marked trend in the use of fossil fuels as a source of primary energy. The low cost of coal has been the main driver for the total dependency of Chile from exporting fossil fuels and the carbonization of the Chilean electric system [32]. In the case of the SIC, the 2013 generation was formed by 38% hydropower (due to droughts in recent years), and 53% by thermal generation (mainly coal and natural gas). The remaining 9% was produced by renewable energies, mainly wind and solar energy [31]. Although the low cost of coal, coal power generation presents negative externalities associated to global and local pollutant emissions [33]. Moreover, Chile has recognized its vulnerability to climate change due to its main productive activities [34].

Notwithstanding the above, Chile is not a major emitter of GHGs in the global context. Considering only CO_2 emissions from combustion of hydrocarbons, Chilean emissions are about 0.2% of the world emissions, ranking at 61st in the world ranking for per-capita- CO_2 emissions in 2008, with a value of 4.35 t CO_2/capita [34-36]. This percentage has remained constant during the last years, but the country's emissions are increasing significantly, mainly due to their growth in the energy sector [34,36].

Regarding prices, in Chile, energy prices for large consumers (with a level of consumption over 2,000 kW) are determined by bilateral agreements between parts. In the case of energy supply to end-users whose connected power is less than or equal to 2,000 kW, the price is established by regulation. Customers that make up this market segment are called regulated customers. In this case, the Chilean electricity law distinguishes prices at generation, transmission, and distribution levels. At the generation level, the price is regulated based on “regulated nodal prices”, which are set by the Chilean Energy Commission twice a year, in the months of April and October of each year. Nodal prices have two components: the first, called basic price of energy, corresponds to the average in the time of the marginal costs of energy from the electric system, operating at the minimum total cost; and the second, called the basic price of the peak power, corresponds to the annual marginal cost of increasing the installed capacity of the electrical system, considering the cheapest generating units to provide additional power during the electrical system’s peak demand hours of the year, increased by a percentage equal to the theoretical power reserve margin of the electrical system [12]. It is worth to mention that, in the last ten years, marginal costs and end-users’ energy prices have considerably increased due to the lack of new generation and transmission projects, among other variables [32]. Indeed, in the last four years, the residential customers have seen growing up their energy price by 20%.

In this context, the Chilean government has proposed to introduce a carbon tax of 5$/ton$CO_2$, in the frame of a tax reform that is discussed these days in the National - Congress. Accordingly, we measure the main impacts of the proposed carbon tax in the SIC (main Chilean grid), for the period 2014 – 2024, and compare the optimal power generation matrix, the system average annual marginal cost, and the level of CO_2 emissions, in the presence and in the absence of this carbon tax. In this way the operation of the SIC using the OSE2000 software, which is the software employed by the Chilean National Energy Commission to set regulated nodal prices, was simulated.

1.7.3 Mathematical modeling through OSE2000

The OSE2000 model simulates the optimal operation of hydrothermal power system, through the optimization the inter-temporal operation of existing water reservoirs in the system, with an objective function that minimizes the expected costs of operation, maintenance and failure for the full system. The optimization procedure is based on Stochastic Dual Dynamic Programming, as detailed below in this section. As a multinodal model, it is considered to solve the problem, the transmission constraints and the losses that occur in the lines. As a result, the model provides the optimal economic dispatch of all generating units, the flow through each of the modeled lines and the marginal costs applicable to each nodes of the electrical system. So, it is possible determine the prices of electricity in each consumption bar. It is important to point out that the OSE2000 system considers multiple possible hydrologic scenarios, which affect differently in the inter-temporal operation of water reservoirs belonging to the analyzed electric system.

The modeling horizon is defined by the user and typically corresponds a ten years period. This horizon is divided into two seasons, the first one runs from October to April and the second one from April to October each year. In relation to the power demand, OSE2000 considers a projected demand to the complete period of analysis and to each node of the system. Moreover, this demand's projection is separated in three blocks: high, medium and low demand. The projection of the electric demand is generated by the CNE on the basis of historical information and the growth estimate for each node in the following years [123].

New generation plants and transmission lines are exogenously defined and provided to the OSE2000 software as parameters. The power plants are classified in hydraulic, thermal and renewable [123]. Each of these power plants has an operation's price (marginal cost), consisting on two components: the fuel cost and the non-fuel variable cost. Renewable power plants include solar, wind, biomass and geothermal sources.

The problem that is solved by OSE2000 corresponds to a Piece-wise Linear Stochastic Dual Dynamic Program, where the objective function consists of minimizing the expected costs of operation, maintenance and failure of the system, assuming an optimized inter-temporal operation of reservoirs in a hydrothermal system is determined. It should be noted that the ability to store water in reservoirs greatly increases the complexity of the problem, basically because it is necessary to jointly assess the inter-temporal use decisions of dammed water, and its opportunity cost in time, according to weather forecasts associated to each hydrologies included in the analysis. Thus, the process of optimization of the system's operation in a specific year influences the optimal to the operating system for the following years. So, OSE2000 allows modeling the operation of a hydrothermal, multimodal and multireservoir electrical system and optimize its operation over a given period. As outcomes OSE2000 provides the optimal economic dispatch of all generating units, the power flow through each of the modeled lines and the marginal costs in each node of the system. All these variables are disaggregated for different simulated hydrologies for each year (53 hydrologies in this work), and each period and demand block. OSE2000 is the official model used by the Chilean National Energy Commission to optimize the operation of the SIC and the SING. The mathematical formulation of the optimization problem that solves OSE2000 is presented below [124].

$$Z^* = min \sum_{t=1}^{N_T} \sum_{s=1}^{N_s} P_{t,s} * (C_{t,s} * X_{t,s} + (1+d)^t * f_T * (X_{T+1,s}))$$

s.t.

$$A_{t,s} * X_{t,s} + E_{t,s} * X_{t+1,s} = B_{t,s} \;\; \forall\, 1 \le t \le N_{T-1}\, ; 1 \;\le s \le N_s$$

$$A_{T,s} * X_{T,s} = B_{T,s} \;\; \forall\, 1 \le s \le N_s$$

$$\check{X}_{t,s} \le X_{t,s} \le \hat{X}_{t,s} \;\; \forall\, 1 \le t \le N_{T-1}\, ; 1 \le s \le N_s$$

$$\check{X}_{T,s} \le X_{T,s} \le \hat{X}_{T,s} \;\; \forall\, 1 \le s \le N_s$$

Where,

Z^* : expected cost of system operation

d : discount rate

t : step time

s : simulation sequences

N_s : number of sequences of hydrological simulation

N_T : number of decision steps in time

Then, for each stage of decision t and simulation sequence s:

$A_{t,s}$: electrical connectivity matrix

$E_{t,s}$: hydraulic connectivity matrix

$P_{t,s}$: probability of sequence s in the stage t

$C_{t,s}$: vector and penalty costs

$B_{t,s}$: vector of right side

$X_{t,s}$: state vector

$\hat{X}_{t,s}$: maximum restrictions vector

$\check{X}_{t,s}$: minimal restrictions vector

$f_T * (X_{T+1,s})$: future cost function at the border for the simulation sequence s and T stage (last stage of simulation)

The optimization problem described above has a large size because it grows up exponentially with the number of water reservoirs and the steps considered in the simulation. So, some techniques to reduce its complexity, and resolve the problem, are necessary. To do that, OSE2000 uses a Benders decomposition technique, which allows for the solution of the optimization problem of the hydrothermal system, using an iterative algorithm, wherein the steps for solving the problem are decoupled. The algorithm represents the future operation through a relaxed function of future costs for each decision stage [124]. In order to solve the problem in a reasonable computational time, OSE2000 uses two stages. The first stage corresponds to the iterative process, 50 iterations, where the main objective is obtaining the value of water (opportunity cost) for the different stages of simulation time. The value of the water resulting from the first stage serves as the input to the second stage, where the operation of the complete system is simulated. More details about the modeling of OSE2000 can be found in (Sauma et al., 2011) [125].

Using the described software, we compare the effectiveness on reducing CO_2 emissions of carbon taxes and of some energy efficiency measures in the electrical sector. To assess the impact of introducing a carbon tax in this optimization model, the private costs of thermal power plants were altered, to account for the increase produced by the tax. CO_2 emission rates were considered for each thermal plant according to the type of fuel used for generating electricity. As a way of doing a sensitivity and comparative analysis, we simulate different levels of carbon tax, not only a level of 5$/Ton CO_2 as proposed in the tax reform. In the same way, several scenarios of demand response in the residential sector, produced by mechanisms to encourage EE, were simulated. The period considered was 2014-2024. The results obtained were compared in terms of the type of power generation, the average marginal cost of the system, and the reduction of CO_2 emissions. The results obtained are presented in the next section.

1.7.4 Results obtained

Comparing the effectiveness on reducing CO_2 emissions of the carbon taxes and of some energy efficiency measures in the electrical sector, it has been possible to show that the introduction of some energy efficiency measures reducing 2% of the power demand of the residential sector could achieve larger reductions in CO_2 emissions than the imposition of the proposed carbon tax, while simultaneously decreasing the price of energy. Moreover, when a 5$/Ton$CO_2$ tax is introduced and a 2% reduction of the projected demand is jointly considered, the reduction in CO_2 emissions is smaller than when considering only a 3% reduction of the projected demand (with no imposition of any carbon tax). This suggests that promoting EE measures may be a more cost-efficient way to reduce CO_2 emissions than carbon taxes since they are effective in reducing CO_2 emissions and they do not increase the marginal cost of energy production, as carbon taxes do. This last conclusion is very important in the case of Chile, where energy prices are ones of the highest in the Latin-American region. Therefore, considering the characteristics of the Chilean power sector, the projected demand growth for the coming years, the current levels of energy prices, and the growing economy and competitiveness of Chile, our results suggest that the introduction of a carbon tax may not be the best way to reduce CO_2 emissions in Chile at this moment. Our results suggest that introducing EE measures in the residential sector would better achieve this aim, keeping or reducing energy prices.

2. PAPERS

2.1 DESIGN OF A METHODOLOGY FOR IMPACT ASSESSMENT OF ENERGY EFFICIENCY PROGRAMS: MEASURING INDIRECT IMPACTS IN THE CHILEAN CASE.

Design of a Methodology for Impact Assessment of Energy Efficiency Programs: Measuring Indirect Impacts in the Chilean Case.

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Abstract

Today many countries are promoting energy efficiency (EE) measures as part of their energy strategy. Among the goals sought with these actions are: producing a decoupling between economic growth and energy consumption, reducing the dependence on fossil fuels as a primary energy source, and reducing greenhouse gas emissions. Measuring these market transformation effects of EE programs is crucial. However, in the current literature and practice, assessments of EE programs have focused on direct impacts (i.e., impacts whose energy savings can be directly quantified) due to their objectivity and simplicity to put evaluations in a cost-effectiveness framework. Moreover, when attempting to study the indirect effects of EE programs, assessment methodologies basically focus on identifying the effects and, at most, quantifying a proxy of the effects in terms of the number of activities developed or the number of people attending EE training or dissemination events.

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We propose a methodology to assess the impacts of EE programs, especially focusing on indirect effects (i.e., effects not generating immediate energy savings). We focus on those indirect effects having the capability of mobilizing long-term energy savings through market transformations in energy markets. We attempt to measure the potential future energy savings that are sustainable in the long term due to a behavioral transformation of energy markets. In order to measure these indirect effects, we use three axes: Presence, Valuation and Mobilizing capacity. This methodology was applied to 12 EE programs (implemented during 2011 and 2012 in Chile) in order to obtain their indirect impact assessment.

Key words: Efficiency, Public Programs Design, Impact Evaluation Methodology, Indirect Impacts.

JEL Classification: C18- C81- D04- D61-H30

1.- Introduction

Today many countries are implementing initiatives aimed at promoting a more efficient use of energy in different sectors. These measures are part of what is called Energy Efficiency (EE), defined as a set of actions that optimizes the relationship between the amount of energy consumed and the quantity of final products and services obtained (Vera et al. 2013). There are various mechanisms to promote EE. Among them, we can mention flexible electricity pricing systems; labeling of products such as appliances and automobiles; establishment of energy consumption standards in manufacture equipment and air conditioning; energy management processes; replacement of luminaries; old buildings reconditioning; improvement in construction's materials; and EE information and training programs.

Generally speaking, the ultimate goal of EE programs is to produce a market transformation that is capable of producing a decoupling between economic growth and energy consumption, reducing the dependence on fossil fuels as a primary energy source, and reducing greenhouse gas emissions. Consequently, measuring the long-term market transformation effects of EE programs is crucial. Moreover, when public monetary resources are used to implement those EE programs, the assessment of these market transformation effects are even more relevant.

However, in the current literature and practice, most methodologies for assessing the effects of EE programs have only focused on direct impacts (i.e., impacts whose energy savings can be directly quantified) due to their objectivity and simplicity to put evaluations in a cost-effectiveness framework. For instance, Henriksson and Söderholm (2009) rank EE programs according to the energy savings obtained from a cost-benefit analysis, considering only the direct short-term effects of the programs.

Although some authors (Blumstein et al. 2000) recognize the existence of indirect impacts of EE programs, the assessment methodologies used by them basically focus on identifying the effects and, at most, quantifying a proxy of the effects in terms of the number of activities developed or the number of people attending EE training or dissemination events.

We propose a methodology to assess the impacts of EE programs, especially focusing on indirect effects (i.e., effects not generating immediate energy savings). Specifically, we focus on those indirect effects having the capability of mobilizing long-term energy savings through market transformations in energy markets. That is, we attempt to measure the potential future energy savings that are sustainable in the long term due to a behavioral transformation of energy markets. In order to measure these indirect effects, we use three axes: Presence, Valuation and Mobilizing capacity. Contrary to common current methodologies, these axes allow collecting information regarding the people´s levels of knowledge and perception of EE and regarding the usefulness of different EE mechanisms in people's domestic tasks. Availability of this information is a pre-requirement to transforming energy markets, to make a more sustainable use of energy over time and to generate a suitable base that reinforces future EE actions that can be quantified in terms of effectively reduce energy consumption associated with certain levels of services received.

The proposed assessment methodology is adequate for developing countries like Chile because its design criteria consider the applicability to different types of EE programs, the flexibility to be applied in a modular manner and the simplicity so as not to demand excessive human and monetary resources in its application.

The rest of the paper is structured as follows. Section 2 reviews the characteristics of the main impact evaluation methodologies used both in existing public programs in Chile and in EE programs worldwide. Section 3 describes the methodology proposed, its objectives and scope. Section 4 provides the results of the application of the methodology to 12 EE programs implemented by the Chilean Energy Efficiency Agency (AChEE, for its acronym in Spanish), and a general discussion. Finally, Section 5 concludes.

2.- Review of impact assessment methodologies of EE programs

In the current literature, most methodologies for assessing the effects of EE programs have focused on direct impacts due to their objectivity and simplicity to put evaluations in a cost-effectiveness framework. Henriksson and Söderholm (2009) rank EE programs according to the energy savings obtained from a cost-benefit analysis, considering only the direct short-term effects of the programs. Boonekamp (2006) concludes that most of the time EE is evaluated in reference to direct consumption reductions, i.e., based on the direct impacts. Cui et al. (2014) review different methodologies to evaluate impacts of EE, concluding that these methodologies, in general, have focused their attention on calculating direct energy savings and identifying some influencing factors in the results. The reason for that, according to the authors, is that EE is defined as an efficiency, which implies it must reflect an immediate input-output efficiency gain regarding the energy use. Similar conclusions are provided by Zhou and Ang (2008) by analyzing different models to measure EE impacts. In the same direction, Gabardino and Holland (2009) remark that there is a trend in the impact assessment methods to prioritize quantitative measurement of impacts mainly because quantitative methods produce data that can be aggregated and analyzed to describe and predict relationships among them. However, they recognize qualitative studies may significantly help in explaining contextual differences in those relationships.

Several other authors have pointed out the importance of considering the indirect effects of EE programs. Blumstein (2010) recognizes the significance of measuring the indirect impacts of EE programs and claims that investing in programs with mostly direct impacts and investing in programs with mostly indirect impacts are complementary strategies. Vine (2008) remarks that sometimes evaluators focus on direct effects of EE programs because they are ease to measure, forgetting about the true program goals (which are often harder to measure). This situation frequently occurs in EE education programs. Van Den Wymelenberg et al. (2013) pointed out that EE programs can have some components that involve market transformations, which aim at changing the behavior of individuals and organizations. They recognize that these components are complex and expensive to evaluate, when compared to traditional direct methods, because they require determination of changes in behavior, attitudes, and process development, among others. In the same vein, Palmer et al. (2013) also recognize the significance of measuring the indirect impacts of EE programs and point out the need for separately considering an EE impact evaluation, a process evaluation and an evaluation of the market effects. In addition, Boonekamp (2006) also recognizes that socio-economic characteristics and demand evolution should be considered in an adequate assessment methodology through use of statistical information.

In the next subsections, we present a review of the EE-programs' assessment methodologies used in Chile and in the US.

2.1. Review of impact assessment methodologies used in Chile

In Chile, until 2012, there were several general methodologies for impact evaluation of public programs, but none of them was specifically designed for evaluating EE programs. Recently, in 2013, the AChEE adopted the International Protocol of Measure and Verification, IPMVP, (Efficiency Valuation Organization 2012) as the official methodology to assess the direct impacts of its EE programs. However, there were not assessment methodologies to evaluate the indirect effects of EE programs before this work. Previously, the indirect effects of EE programs were evaluated by adapting other assessment methodologies (that were designed to evaluate other type of public programs). The main two assessment methodologies previously used in Chile to evaluate the indirect effects of public programs are the methodology designed in 2009 by the Chilean Budget Direction, DIPRES (Chilean Budget Direction 2009) and the Logical Framework methodology presented and systematized by the Latin American and Caribbean Institute for Economic and Social Planning, ILPES (Latin American and Caribbean Institute for Economic and Social Planning 2005).

Next, we analyze these two assessment methodologies from the point of view of their applicability to EE programs in Chile. The applicability of the revised methodologies is determined on the basis of the simplicity of use, the amount of monetary and human resources to be allocated for their correct application and the diversity of types of programs and projects of EE to which they can be applied.

The methodology used by DIPRES was created with the aim of measuring the effectiveness of the outcomes at different levels, considering issues of efficiency and economy of the public programs evaluated. It is oriented to governmental agencies that are in charge of the design, implementation, monitoring, control and evaluation of programs with public funds. As a tool, it considers the evaluation of quantitative and qualitative variables and it raises the need for assessment and measurement of short-, medium- and long-term effects. It defines three levels of outcomes to assess: Product Level, or short-term results, Intermediate Level, or medium-term outcomes related with the changes in behavior, skills and abilities (that is, the formation of human and social capital), and Final-Results Level or Impact Level, which refers to those effects achievable in the medium and long term. The main advantages of DIPRES's methodology for assessing impacts of EE programs are its applicability to a wide range of public programs and the consideration of assessments at different levels of results and moments in time. However, an important disadvantage is the large request for information of the programs, individuals and organizations both participating and not participating (control groups) in the programs. These massive information requirements translate into significant cost, which may represent a significant fraction of the total budget of the program itself in cases of small programs or low-budget programs.

On the other hand, the Logical Framework methodology is defined as a tool to support the processes of planning, monitoring and evaluating projects and programs. The core of the methodology is a clear and explicit definition of strategic objectives or main goals to be achieved through the implementation of the program or project. The methodology facilitates the process of conceptualization, design, implementation and evaluation of projects and programs, with a strong orientation to the definition of objectives delineating the project activities in any of their stages. It includes steps for identification, preparation, assessment, monitoring and control of the projects. The main advantage of the Logical Framework methodology is that it is focused on the coherent definition of programs and evaluations. On the other hand, its main disadvantage for evaluating EE programs is that it could be very costly in human and financial resources, because it is very intensive in time dedication for planning activities, especially for pilot programs.

2.2. Review of impact assessment methodologies of EE programs used in the US

Several assessment methodologies are used worldwide to evaluate the impacts of EE programs. The most commonly used in the US are the International Protocol of Measure and Verification, IPMVP, (Efficiency Valuation Organization 2012), the Model Energy Efficiency Program Impact Evaluation Guide (U.S. Department of Energy 2007), The California Evaluation Framework (The California Public Utilities Commission 2004), The California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals (The California Public Utilities Commission 2006) and The EERE Guide for Managing General Program Evaluation Studies and Impact Evaluation Framework for Technology Deployment Programs (U.S. Department of Energy 2006).

The International Protocol of Measure and Verification, IPMVP, is a guide that presents a framework and four measurements and verification (M&V) options for reporting of energy savings, thereby allowing a project to be transparent, accountable and coherent. The M&V activities considered are: analysis of the facilities, energy metering, monitoring of independent variables, and the calculation and reporting of energy savings. IPMVP has been proposed as a guide for professionals who must necessarily get involved in a prior design M&V Plan. The main advantages of IPMVP are that it provides specific methods for evaluating projects in the EE field and that it reduces information asymmetries among the actors by permanently adopting it as part of the evaluation methodology. On the other hand, some disadvantages are the facts that it requires full adoption of this guide to use it as a reference, it applies only to direct impacts and it includes additional implementation costs associated with the management and control of the guide itself.

The Model Energy Efficiency Program Impact Evaluation Guide has been developed to assist the implementation of the National Plan for Energy Efficiency of the Department of Energy of the US (DOE). This guide describes several models to calculate energy savings, demand for energy and global emissions, which can be applied to EE programs that are implemented at state, city or company level in the US. This guide recognizes that there are different types of EE programs and proposes three types of ex-post assessments: impact evaluation, process evaluation and evaluation of market effects. The main advantages of this methodology are that it provides specific methods for evaluating projects in the EE field and it is based on the implementation of the IPMVP as part of the evaluation. Its main disadvantages are that it requires full adoption of the methodology if you want to use it as a reference, it requires a communications plan that allows program managers and evaluators to develop and communicate a clear understanding of the methodology, and it must consider the costs associated with management and the control of its implementation.

The California Evaluation Framework has been prepared by The California Public Utilities Commission (CPUC) and the Project Advisory Group. It provides a consistent, systematic and cyclical planning and it establishes the basis to perform evaluations of the EE programs in California. The design considers the review of some assessment protocols used in California or other places. This framework was designed to serve as a roadmap, providing practical guidance to program managers in order to plan their assessment efforts consistently with the needs of the CPUC and other stakeholders programs. It also facilitates the comparison among the effects of different programs by measuring them. This methodology can be used in the assessment of direct and indirect impacts. In the first case, the purpose is to verify energy savings reached directly by the program while, in the case of indirect impacts, it is recommended to establish a baseline in order to study and compare with a post-measure study to evaluate the effects of the program. Its main advantage is that it defines a comprehensive framework to assess different types of programs, and its main disadvantage is the high requirement for monetary and human resources to implement the methodology.

The California EE Evaluation Protocols were prepared in 2006 by CPUC and the Project Advisory Group in order to be a guide to evaluate the California EE programs that started in 2006. These protocols are based on the California Assessment Framework and cover assessments of direct and indirect impacts, including effects on the market, emerging technologies, codes, standards and processes. Its main advantage is that it constitutes a detailed and specific protocol for EE programs evaluation. As well, its main disadvantage is the high requirement for monetary and human resources to implement the protocols.

The EERE Guide for Managing General Program Evaluation Studies divides the process of program evaluation in 14 steps very easy to understand. These steps are grouped into two major phases: (i) planning and design of the evaluation and (ii) management and dissemination of evaluation results. Its main advantages are that it helps to have a notion of the program's performance based on their goals and that it can be applied to a wide range of programs. However, its main disadvantage is that it does not contribute significantly to the development of specific evaluation plans because it assumes that this is a task of the consultants running it.

As it is seen here, most methodologies or protocols are focused mainly on the assessment of the direct impacts of the EE programs, although some of them recognize the need for orienting the evaluations to measure indirect impacts. Generally speaking, all these methodologies expect reporting and measuring the effects of the EE programs and, in this way, allowing the verification of the goals, helping to understand why effects happen, identifying ways to improve current programs, and helping in the selection of future programs. Most of these methodologies are intended to evaluators and professionals that are involved in the design and evaluation of EE programs and, thus, their objectives are to increase cost-efficient investment in EE projects through minimizing information asymmetries associated with the results of these projects. In some of these protocols, the existence of different types of programs is recognized (resource acquisition, market transformation, codes and standards, education and training, and multiples targets).

From the point of view of their applicability in developing countries, the main advantage of these methodologies is the consideration of specific methods to evaluate projects in the EE field. Their main disadvantage, however, is that they generally require full adoption, especially if used as a reference, which may represent a budget problem. Nonetheless, in some cases where a win-win situation can be achieved, EE measures may be carried out by programs funded by governmental institutions as a way of improving social welfare (Allcott and Greenstone 2012). In those programs, it is fundamental to generate policy guidelines, instruments and energy programs that facilitate the coordination among different players in the industry, including consumers, producers and government authorities (Delina 2012).

3.- Design of a methodology to evaluate the impacts of EE programs

After reviewing some existing methodologies for the evaluation of direct and indirect impacts, we propose a methodology for evaluating EE programs. We especially focus on those indirect effects having the capability of mobilizing long-term energy savings through market transformations in energy markets. In order to measure these indirect effects, we use three axes: Presence, Valuation and Mobilizing capacity. The proposed methodology also considers relevant aspects for its application in developing countries (such as the impact assessment of programs implemented as a pilot, low budget for their implementation and evaluation, and the applicability to a wide range of programs and types of interventions). Accordingly, the design of the methodology for assessing impact of EE programs is based on the following criteria: Applicability, defined as its ability to be applied to different types of EE programs in various sectors of the economy, and to measure both direct and indirect impacts; Flexibility, understood as its ability to be applied in a modular fashion either to complete programs or some of their components, or to each of the projects associated with the implementation of the program; and Simplicity, defined as the ability to establish itself as a practical and detailed guide, easy to apply to different types of EE programs. Thus, the ultimate goal of this methodology is to promote the proper evaluation of the results of EE programs with direct and indirect impacts, in order to generate reliable information to support decision makers regarding the effectiveness and continuity of programs, as well as, regarding the feedback design process and the implementation of instruments that promote the efficient use of energy.

In this section, the methodology designed is described. First the general framework, where the methodology is contextualized, is presented. This framework has three different levels: strategy level, program level and evaluation level. Since the methodology is especially focused on the evaluation level, we only provide here a brief description of the strategy and program levels.

3.1. General framework of the methodology

The proposed methodology is developed in a general framework, basing the programs and their evaluations according to the strategic objectives and guidelines of the institution that will carry them forward. This general framework is composed of three parts: Strategy Level, Program Level and Evaluation Level, as illustrated in Fig 1.

The Strategy Level consists of all actors, functions and processes that define and deliver policies and strategic guidelines for EE programs and projects to be developed. Consequently, EE programs must be evaluated in view of their consistency with those policies and strategic guidelines. This level also provides resources for the design, implementation, execution and evaluation of these programs and projects. Thus, this level provides inflows to the processes carried out at both program level and evaluation level, which are represented by the arrows in the left-hand side of the diagram in Fig 1.

Moreover, this level is fed by the level of programs, from the information generated in the processes of design, implementation and execution of them, as well as by the level of evaluation, using information generated from the results of impact assessments. This information flow is represented by arrows on the right-hand side of the diagram in Fig 1.

The Program Level considers the design and redesign, implementation and execution of programs. It obtains information and resources from the strategy level, it provides information to the evaluation level through reports and the experience gained in these processes, and it is fed by the evaluation level with the information generated as a result of the assessment. These information flows are explicit by the arrows on the right- and left-hand sides of the diagram in Fig 1, respectively. At this level, it is highly recommended to develop the design of the program considering the definition of a theoretical framework that provides support and coherence to the program itself, its goals and activities. As well, we suggest developing a preliminary design of the evaluation at this level, so processes and activities are prepared and executed in such a way that the assessment of the impact is facilitated and the results have the highest possible level of reliability given the available resources.

Both the strategy and the program levels have been included in areas delimited by dotted lines in Fig. 1, representing that the design of the methodology of impact evaluation does not include the processes developed inside them. Instead, the scope of the proposed methodology includes only the processes occurring within the evaluation level.

The Evaluation Level considers the core processes of this methodology, comprised of four basic steps that are fed with information from the strategy and program levels. These four steps also provide feedback to the previous (more strategic) levels. We assume these four steps sequentially for purposes of description of the methodology and, therefore, they have been connected with unidirectional arrows in Fig 1. However, each of these steps can go down to another if necessary. The following subsections describe these four steps proposed to be considered in the evaluation level.

3.2. Step 1. Analyze the design and background of the program, project or component

In this step, it is carried out an analysis of all relevant information regarding the design and implementation of the program, and the preliminary design of the evaluation, if it exists (see Fig. 2).

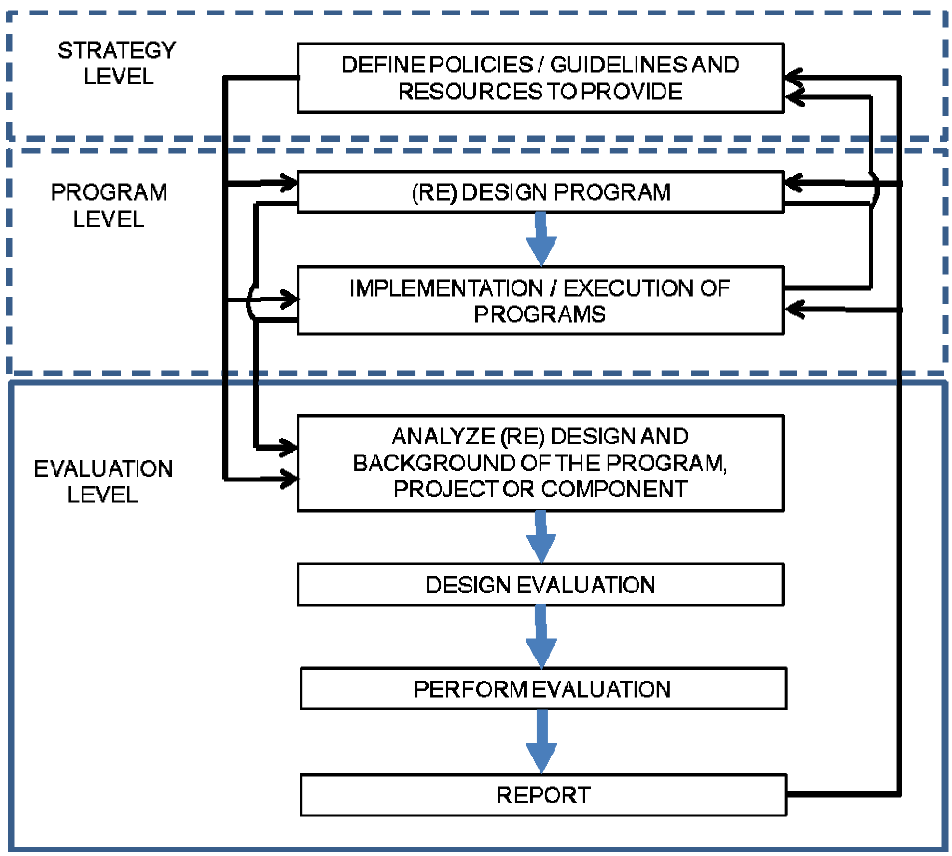


Fig. 1. General framework of the methodology for impact evaluation of EE programs

This step contains a review and analysis of the description of the program, project or component to be evaluated and an analysis, if it is possible, of the theoretical model giving foundation and coherence to the objectives, activities and program goals. In the absence of the theoretical model, the evaluator should generate it based on their experience and the information available. This first step also considers the identification of the objectives and desired effects of the program, as well as the goals, indicators and variables declared in the program design. In this way, it can be clearly established the questions the evaluator wants to answer through the impact evaluation. This step also includes an analysis of the causal relationships that originated the program and determined the activities developed. The identification and characterization of the relevant program variables, both those present in the causal relationships and those that are not present, are also considered in this step. We include variables that are not present in the causal relationships because they can be a source of distortion of the obtained results. This step also includes a review of the preliminary impact evaluation guidelines defined in the program design, if it exists, regarding the implementation and final execution of the program. Finally, the step considers an analysis of any other aspect of the design or implementation of the program, project or component that provides important background information that must be taken into consideration in the design and implementation of the evaluation.

In this way, it is generated a description of the program that includes a clear definition of the goals, objectives and strategies associated with the program, project and/or component, and the way the program was designed and implemented to achieve the proposed goals. This description facilitates the subsequent design of the evaluation plan because it helps to identify the issues that need to be evaluated, how the evaluation should be carried out and the best way to collect the required data, depending on the type of program to be evaluated. One way to accomplish this description is by using the theoretical framework of the program, in case that the program design includes it. Otherwise, the theoretical model of the program must be defined at this step of the evaluation, making explicit the causal relationships among its different elements and the goals to achieve with the program. This theoretical framework should be built at the program level, at the design or redesign stage.

3.3 Step 2. Designing the program, project or component evaluation plan

At this step, the final design of the evaluation plan is developed. This plan must define the evaluation objectives, identifying the questions to be answered in the evaluation (e.g. What is the objective of the evaluation? What type of results is expected to obtain? How will the results be used? What is the relevance of the information to obtain?). The plan also sets the audience of the information, including its main features and requirements of both content and format and define the scope of the evaluation and the level of reliability of the results. These definitions must be coherent and consistent with the resources available for evaluation. Accordingly, here it is necessary to ask what information is required and what level of detail is required. In these questions, it should be considered that the results of the evaluation will be used to support the continuity and expansion of a program through verification of their impacts, or to support investment decisions to produce more energy saving, or to provide feedback on program design or some of its components to increase its effectiveness. Thus, it should be clearly stated the purpose of the evaluation carried out, identifying key stakeholders and the sector to which they belong. Additionally, this plan must determine the resources available for the evaluation, including monetary, human resources, time, skills, etc. In particular, once human resources available for evaluation are established, the roles and responsibilities of each one of the agents involved should be defined. It is also required to determine the aspects and variables to assess, in order to design the evaluation plan. It is necessary being precise in these definitions because the results may have several uses and recipients. This implies carefully selecting the activities to be evaluated according to the objective of the evaluation plan and the theoretical framework that describes the program. In the case that the design and implementation of the program is being evaluated, an intermediate evaluation may be conducted, corresponding to a process evaluation where those activities that lead to the achievement of the overall goals of the program are evaluated and where there is a focus on the target audience interest. Finally, this plan must select the measuring methods to be used according to the type of program, project or component and the type of variables to be measured. This task includes identifying the questions to answer and metrics to use, defining indicators, according to what evaluators want to measure and the goals of the program, project or component; and scheduling the activities contained in the evaluation plan (see Fig.3).

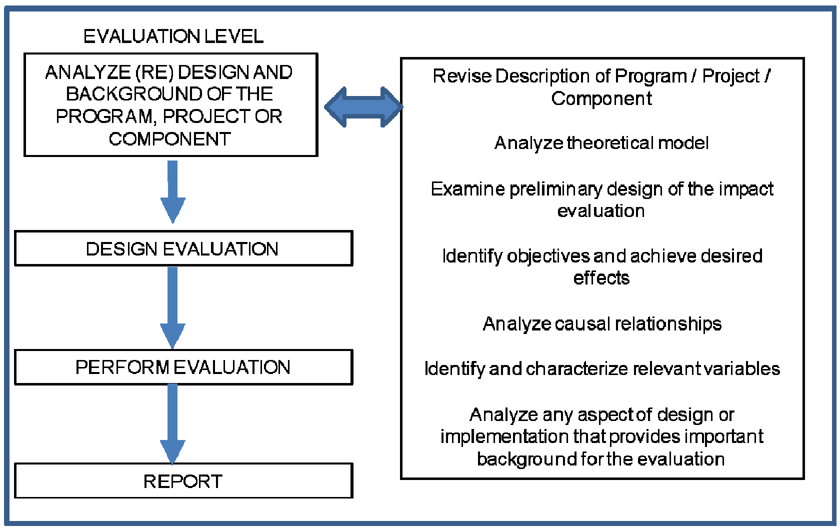


Fig. 2. Step 1.Analyze the design and background of the program, project or component to evaluate

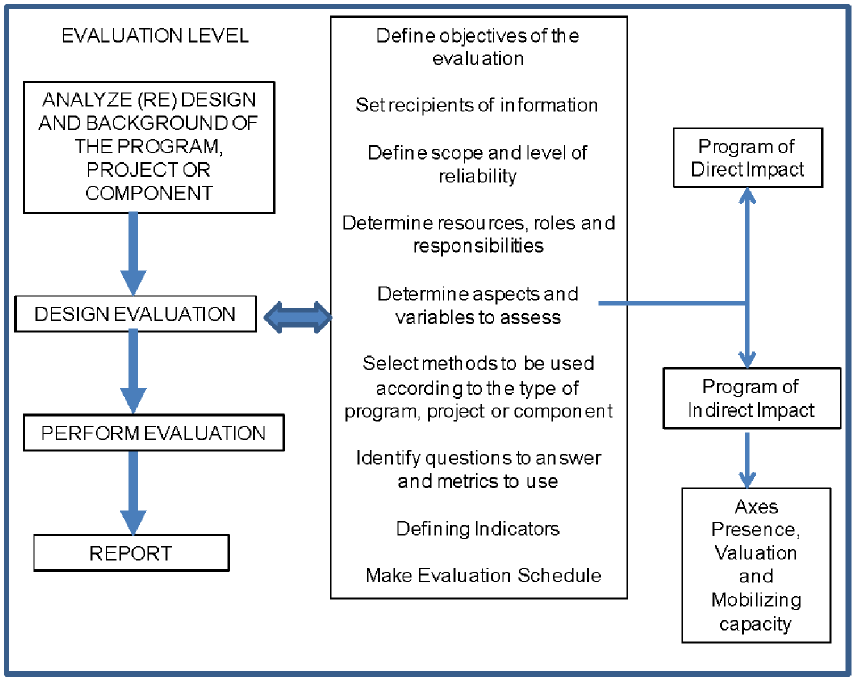


Fig. 3. Step 2: Design of the program, project or component evaluation plan

3.3.1. The objective of the evaluation and the types of impacts to be measured.

Depending on the objectives pursued with the evaluation of a program or any of its components, the evaluation plan focuses on assessing direct or indirect impacts (or both). The main goal of a direct impact assessment is to obtain an estimation of the net energy savings achieved as a direct result of the program, project or component, in the most accurate and unbiased way possible, given the information available, the level of reliability of the required information and the resources that are available to develop the assessment. Since energy consumptions, and not energy savings, are truly measured; to determine the net energy savings, it is necessary to measure the change in the energy use of a system subject to a participant EE program through a certain period of time and, then, estimate from there which would have been the energy consumption of the participant, in the absence of the EE program. Depending on the type of energy involved in the program, the net energy savings can be measured in terms of kWh, gallons of fuel, thermal units of gas, etc.

Different methods can be used to evaluate the direct impacts of programs. These methods can be classified in engineering methods and methods of billing analysis. The decision of which method use, should consider criteria such as the specific type of program, the available resources, data collection costs, the reliability level required for the resulting information, the size of the program, project or component to evaluate and the existence of similar evaluations previously developed. Engineering methods are preferred when there is no billing information before program implementation. This occurs, for example, when programs are aimed at promoting EE in new buildings, facilities or technologies. Engineering methods are also recommended when it is expected that the effects achieved by the EE program were small so they are not distinguishable in billings. This usually occurs when consumption savings due to the program, project or component are less than 10% of the typical total bill, or when program participants are too heterogeneous. On the other hand, methods based on billings will be preferred when the data of the corresponding bills before and after the program implementation are available, when estimated program effects on savings are of a magnitude easily detectable from billings analysis, and when program participants are relatively homogeneous.

In the case that the evaluation plan focuses on assessing indirect impacts, existing assessment methodologies typically only identify and classify the effects and, at most, they propose to estimate the impacts by the number of participants in program activities such as the number of attendees at outreach or training activities or by the number of hours of courses taken. On the contrary, our methodology proposes the estimation of those indirect effects having the capability of mobilizing long-term energy savings through market transformations in energy markets. That is, we attempt to measure the potential future energy savings that are sustainable in the long term due to a behavioral transformation of energy markets. In order to measure these indirect effects, we use three axes: Presence, Valuation and Mobilizing capacity. Thus, contrary to common current methodologies, these axes allow collecting information regarding the people´s levels of knowledge and perception of EE and regarding the usefulness of different EE mechanisms in people's domestic tasks. Availability of this information is a pre-requirement to transforming energy markets to make a more sustainable use of energy over time and to generate a suitable base that reinforces future EE actions that can be quantified in terms of effectively reducing energy consumption associated with certain levels of services received.

Each of these three axes has dimensions and attributes by which it is evaluated. This is measured through different methods of data collection (surveys, structured or semi-structured interviews, and focus groups, among others). In each data-collection method, appropriate questions should be selected depending on the characteristics of the method, the attribute to evaluate, and the interest group (IG) to be evaluated. When constructing questions and metrics, it is important to recognize that some metrics will directly contribute to the reporting requirements of the organization for which the evaluation is made and some other metrics will only contribute in an indirect way. This is relevant because metrics directly contributing to the reporting requirements may be comparable over time.

It is important to note that the metrics used should allow translating concepts into numbers, so the evaluation results are properly reported. For example, when a question is used regarding how often a person has spoken about certain program, the evaluator should establish ranges of answers classified from the most favorable to the most unfavorable results, which depend on the indicators defined in both the program design and the evaluation design.

Since this methodology focus on the assessment of the indirect impacts of EE programs or some of its components or projects, we now present a detailed description of the dimensions and attributes of each axis used to measure the indirect effects. For the same reason, the rest of the paper focuses on the indirect impacts of EE programs.

3.3.2. Presence axis

It corresponds to the way the EE program and its actions are present in the minds of people or IG associated with the program. This axis has two dimensions: notoriety and scope. The notoriety is measured by two attributes: penetration and intensity. Penetration is the amount of people who know about the EE program, while intensity is the amount of times the program is mentioned in a social setting or broadcast network. These two attributes allow estimating how notorious the EE program is. The type of questions used in an interview (or other data collection method) to get information about these attributes can be, for example: Do you know the program or technology? On average, how many times (number of interactions or social meetings) you talk about the program with colleagues or friends within a month?

On the other hand, the scope is measured by the number of interactions occurring among members of different layers of exposure to the EE program. Let's define the "Core" as the set of people who are directly exposed to the EE program (i.e., who begin the diffusion process). Then, we define the "first layer" as the set of people who interact with people belonging to the core, the "second layer" as the set of people who interact with people belonging to the first layer, and so on. Thus, the scope is measuring how far people's interactions can help to positioning an EE program in people's minds (starting from the core and moving towards the first layer, second layer, etc.). Naturally, the amount and quality of information is decreasing when moving out from the core. Some questions used to measure the scope of a program are: How many people have you told about the program last month? What do you generally say about the program?

3.3.3. Valuation axis

This axis represents the value (degree of worthiness or favorable disposition) that the IG assigns to the EE program. This axis has four dimensions: context, relevance, identification and evaluation. The context means the framework in which the program is promoted, such as official events, seminars, workshops, etc. Some questions that can be used in this case are: What is the percentage of the audience that knew about the product or service offered through the EE program media used? What is the percentage of the audience that knew about the product or service offered through a friend's recommendation?

The relevance corresponds to the degree of significance of the program's stated purpose for the scientific research (academic community), public policy (government), production (firms) and daily consumption (people). Some questions that can be used to get this information are: How important is energy efficiency for you? How relevant is this program to help you in efficiently using the energy?

The identification is the degree of consistency between the EE program and the needs and expectations of each IG, regarding energy topics. Suitable questions in this case are: Which unmet needs do you have in the areas of energy efficiency? To what extent does the program take care of these needs?

Finally, the evaluation dimension corresponds to the positive, neutral or negative general assessment given to the program by the IG. In this case, some ad-hoc questions are: Are the attributes of the technology or process that you use more advantageous than the attributes of the technology or process used by your competition? Is the technology or process promoted by the program easy to install?, easy to use? Can the product or process that promotes the program be easily tested? Is it easy to see the results of the use of this technology or process? Finally, the evaluation dimension corresponds to the positive, neutral or negative general assessment given to the program by the IG. In this case, some ad-hoc questions are: Are the attributes of the technology or process that you use more advantageous than the attributes of the technology or process used by your competition? Is the technology or process promoted by the program easy to install? easy to use? Can the product or process that promotes the program be easily tested? Is it easy to see the results of the use of this technology or process?

3.3.4. Mobilizing capacity axis

This axis refers to the intensity of the motivation of the IG to transfer the effects of the EE program to other people and, thus, it refers to the ability of the IG to motivate other people to perform the desired EE actions. This axis has two dimensions: movement and transcendence. The movement has two attributes: the persuasive capacity and the number of reactions to positive responses. The first attribute is the persuasive and convincing capacity of the message delivered by a promoter of the program to generate actions in the receptors; while the second attribute refers to the amount and type of specific positive reactions or responses that are triggered from the receivers of the message disseminated in the program. The types of questions suggested in this case are: What specific actions have you performed due to what you learned on the program? If you had to recommend implementing this program to a person, what concrete actions will you recommend in order to maximize its use? Has your behavior regarding EE been improved because of this program? How?

The transcendence meanwhile has four attributes: predisposition, perseverance, attitude and behavior. This dimension (and its four attributes) is related to the adoption of long-term behavior. Some suitable questions in this case (for the particular case of energy consumption labeling, for instance) are: Do you use the labeling information in the purchase decision process? How do you think this information will influence your future decisions? How much do you agree with the following statement: It is important to look at the energy consumption when purchasing a vehicle?

3.4. Step 3. Performing the evaluation of the program, project or component

In this step, the evaluation plan is implemented according to the specifications in terms of what will be measured, how it will be measured, who will measure it, and when it will be measured. It is recommended to define a person in the plan that will be in charge of the “project evaluation”. This person will be responsible for managing the evaluation and shall ensure the realization of all specified tasks and products associated with the evaluation and the expected outcome of the assessment. Furthermore, having a specific evaluation unit or an independent consultant for executing the evaluation plan is desirable. In this way, it is avoided that the evaluation is performed by designers, implementers and/or managers of the same program, ensuring objectivity and continuity of the process. Consistently with the above, in this step, it must be selected the audience sample, applied the methods and metrics previously defined, collected data, and done the data analysis (see Fig 4).

3.5. Step 4. Report of the evaluation results

This step consists of reporting the outcome of the assessment. In this step, therefore, it is necessary to produce the required information according to the needs of the recipients of the evaluation, and to write and deliver the final results report (see Fig. 4).

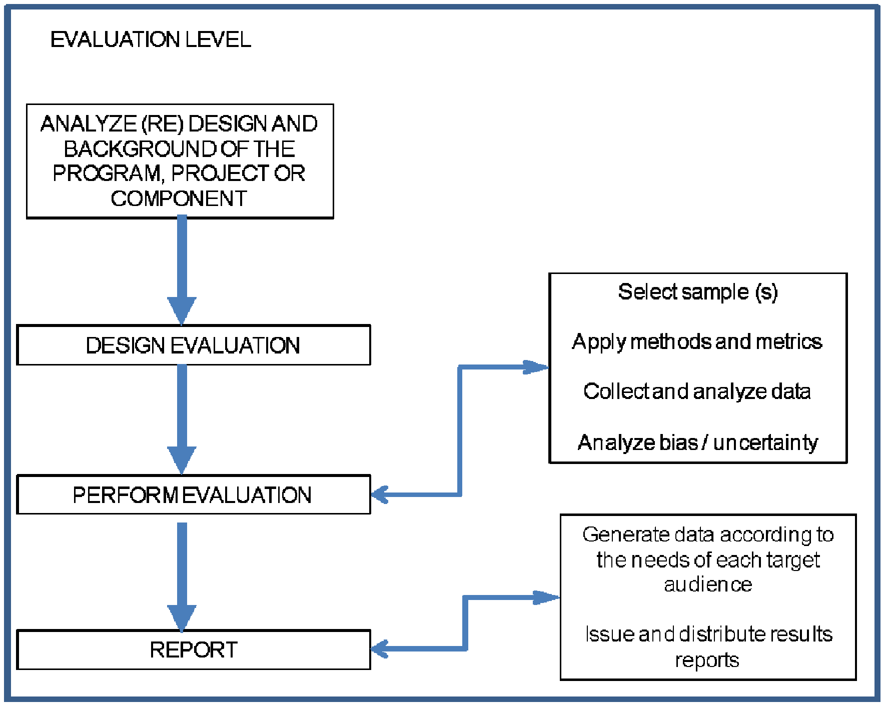


Fig. 4. Steps 3 y 4: Performing the program evaluation and reporting its results

4.- Results of the application of the proposed methodology to the Chilean case.

4.1. Overview of indirect impact evaluation

The proposed methodology was applied to 12 EE programs implemented during 2011 and 2012 by the AChEE in Industry and Mining, Transport, Commercial, Public and Residential, Education and Training, and Measurement and Verification sectors, corresponding to more than 50% of the programs implemented by the AChEE during those years. Since the AChEE has already measured the direct impact evaluations of these programs through the IPMVP methodology, the application of the proposed methodology focused on the evaluation of indirect impacts, based on the three axes already defined. Thus, the evaluation of the considered programs focuses on determining the level of Presence, Valuation and Mobilizing capacity within each interest group (IG) defined as relevant for the assessment. In doing this evaluation, we designed structured and semi-structured interviews, surveys, and focus groups, and we applied them to representative samples of each IG defined as relevant in order to measure the indirect impacts. Table 1 presents an example of the application of these instruments, just to get an idea of the evaluation design.

When reporting the results, we classify the answers to each question asked during the evaluation in three ranges, according to the degree of indirect impact achieved. Specifically, if obtained answers, on average, reached a favorable outcome in a range between 0% and 40%, we define the achieved indirect impact in the assessed axis as LOW; if they were greater than 40% and less than 70%, we define the achieved indirect impact as MEDIUM, if they were between 70% and 100%, we consider the indirect impact as HIGH.

Table 1. Example of the design of an evaluation, regarding aspects to evaluate and data collection methods

Program	Aspects to evaluate	Data collection methods	Objective of the evaluation and questions to ask in order to attain it
Energy Audits	Actions taken as a result of participating in the program to improve the efficient use of energy, such as changing lighting system or equipment	Interviews to a group of program participants	Purpose of the evaluation: Determine the number and type of actions taken as a result of the program. Example questions used to collect information: Did you make changes to the lighting system or to some equipment? How many lights did you change? How many pieces of electrical equipment did you change?

	Level of increased awareness of the potential for energy improvement	Survey (questionnaire) applied in order to measure differences (before and after the program) among the participants. Analysis of the reports of the energy audit.	Purpose of the evaluation: Determine the variation in the knowledge of the people exposed to the program Example questions used to collect information: What is your potential energy savings? What percentage of your costs would you save if you took measures to reach these potentials?

4.2. Results obtained in the evaluation of programs in industry and mining sector

We evaluated four large programs in the Industry and Mining Sector (Encouragement for energy management systems based on ISO 50001; Encouragement for the diagnostics and implementation of EE projects; Pre-feasibility of investments in EE in the industry; and dissemination, training and implementation of cogeneration projects). In order to clearly explain the application of the proposed methodology, we only present a detailed description of the application of the methodology to one particular program. Accordingly, next we describe the results of applying our assessment methodology to the pilot program encouraging the incorporation of ISO 50001.

4.2.1. Step 1. Analyze the design and background of the program "encouragement for energy management systems based on ISO 50001"

This program started in 2011 and it was still under execution at the time the evaluation was performed. The overall objective of the program is to build human capacity to incorporate energy management systems (EMSs) and to promote their use. The program is defined as a pilot program aimed to examine the acceptance level of the introduction of EMSs in the industry.

This program has two components, which can be implemented either by the same company who applies for the ISO50001 standard or by a consulting company. The first one is the implementation and certification of the standard and the second one is the dissemination of the ISO50001 standard and the associate results within the industry and mining sector. From June 2011 to March 2012, the program was born as a pilot implementation. The first certification was awarded in 2012. Interestingly, most of the companies awarded in 2012 with the ISO50001 also participated in other EE programs such as audit and pre-feasibility programs. Regarding the dissemination of the ISO50001 standard, seminars and conferences were held at the main regions of Chile during 2011 and 2012.

The theoretical model underlying the design of the program is based on the goal of generating the necessary human capacity within companies so that they can incorporate and maintain an EMS based on ISO 50001, which allows a more efficient energy use in the long term. This program, in particular, did not have a preliminary design of the program impact evaluation.

4.2.2. Step 2. Designing the program evaluation plan

The main objective of the evaluation is measuring the indirect impacts of the program, considering both companies that are already awarded the ISO50001 standard and those companies that are within the process of being certified. Additionally, another goal of the evaluation is to estimate the potential for replicability of these pilot implementations, through measuring the intentions declared by the people attending some specific seminars.

The impact assessment of the program is designed to collect information that is addressed to the authorities of the AChEE (Director, Deputy Director, Head of Industry and Mining area).

Three IG were defined for the evaluation, depending on the program's and evaluation's objectives, and the type of information required. These three IG are: participating companies that had already been certified ISO50001, companies that, at the time of the assessment, were still in the process of implementation of an EMS, and the participants of the seminars organized by the AChEE during 2011 to promote this program. For the first two IG, in-depth interviews were conducted to the main managers involved in the project. For the third IG, surveys were conducted to a sample of people who attended the ISO50001 seminars organized by the AChEE in several regions of Chile. In this last case, an unbiased random sampling was performed so that more than 10% of the sample universe was covered.

In each one of the three IG, indirect impacts were measured through the presence, valuation and mobilizing capacity of the program. Some examples of the questions asked during the interviews were: How many people in your company know the EMS based on ISO 50001? Have you released to outside the company the results of the pilot experiment conducted in your company? What do you think is the most valuable outcome of implementing the ISO 50001 in your company? On a scale of 1 to 5, where 5 is the highest rating answer: How useful was implementing ISO 50001 for your company? How easy was implementing it in your company? How much do you agree with the following statement: "Using the EMS based on ISO 50001 in your company, you can get a significant level of energy savings"?

4.2.3. Step 3. Perform the evaluation of the program

The collection of information among different IG was performed accordingly with the roles, tasks and calendar set. The data collected from the interviews and surveys were analyzed and the results were presented in a report (summarized below).

4.2.4. Step 4. Report of Evaluation Results

Conclusions of the evaluation program for IG 1: Certified companies.

Regarding the presence axis, the results of the assessment show that the EMS has a large penetration and intensity among the employees of the certified company. This high level of presence was expected because of the regulatory requirements of ISO 50001 and, mainly, because of the advertisement of the certification that the company itself makes within its employees.

A medium level is reached in the evaluation dimension of the valuation axis. This is a consequence of the large amount of information required in the certification process and the lack of adequate training to promote the installation of permanent human capacity within the organization for the EMS maintenance over time.

The mobilizing capacity axis reports a high level of success of the program, in both the transcendence and the movement dimension, since several specific EE actions have been taken after the company got certified.

Conclusions of the evaluation program for IG 2: Participating companies that are in the certification process

Regarding the presence axis, the results of the assessment show that the EMS has a large penetration and intensity among the employees of the certified company. This high level of presence was a little surprising since it might be expected that companies advertise the ISO500001 certification only after getting the certification, and not before. However,

results show that, at least during the first years of implementation, companies do advertise the ISO50001 standards immediately since starting the certification process.
A medium level is reached in the evaluation dimension of the valuation axis. This is due to the good perception of the value associated to the certification on one hand, and the difficulties of getting the information needed to implement the EMS, on the other hand.
The mobilizing capacity axis reports a high level of success of the program, in both the transcendence and the movement dimension, since several specific EE actions have been taken since the company started the certification process.
As Pardo pointed out (2009), we verify that the strategies to improve technology in the industrial sector should be accompanied by training programs on labor standards of EE through EMSs.

Conclusions of the evaluation program for IG 3: Seminar participants
Regarding the presence axis, the results of the assessment show a medium level of success of the program. This is mainly because the seminar attendees do not relate the dissemination of EMSs under ISO 50001 with a program of the AChEE designed to provide technical support for companies wishing to implement these EMSs.
A medium level is reached in the evaluation dimension of the valuation axis, because of the broad spectrum of tasks performed by the seminar attendees.
The mobilizing capacity axis reports a high level of success of the program, in both the transcendence and the movement dimension. However, in this case, several specific EE actions have been taken by the seminar attendees after attending the seminar, but at a domestic level (and not necessarily related with the company where the attendees work).

4.2.5. Evaluation of other programs in industry and mining sector.

Additionally to the encouragement for energy management systems based on ISO 50001, we evaluated other three programs in the Industry and Mining Sector: Encouragement for the diagnostics and implementation of EE projects; Pre-feasibility of investments in EE in the industry; and dissemination, training and implementation of cogeneration projects. The results are summarized in Table 2.

Regarding the encouragement for the diagnostics and implementation of EE projects, the overall objective of the program is to encourage companies to develop energy audits, as a key aspect to the identification of EE opportunities.

Regarding the pre-feasibility of investments in EE in the industry, the overall objective of the program is to encourage the development of economic pre-feasibility studies prior to the realization of EE project investments in the industry.

Regarding the dissemination, training and implementation of cogeneration projects, the overall objective of the program is to plan and prepare cogeneration projects and building national human capacities for the development of such technologies. This program is defined as a pilot program aimed to examine the acceptance level to this type of actions on the industry.

Table 2. Summary of indirect impact evaluation of programs in the industry and mining sectors

Program	IG	Presence	Valuation	Mobilizing capacity
Encouragement for energy management systems based on ISO 50001	Participating companies certified	HIGH	MEDIUM	HIGH
	Participating companies in process to certificate	HIGH	MEDIUM	HIGH
	Seminar participants	MEDIUM	MEDIUM	HIGH

Encouragement for the diagnostics and implementation of EE projects	Companies that conducted energy audits	LOW	HIGH	N/A
Pre-feasibility of investment in EE in the industry	Participating companies	N/A	LOW	HIGH
Dissemination, training and implementation of cogeneration projects	Participating companies	N/A	MEDIUM	LOW

After performing all these evaluations in the industry and mining sector, we verify that, as pointed out in (Alvial et al. 2011), to promote the success in the EE programs, it is necessary to have a multidimensional view, considering cultural, symbolic, affective and discursive aspects of the agents involved in the system intervened.

4.3. Results obtained in the evaluation of programs in the transportation sector

We evaluated the indirect impacts of three programs in the transportation sector. The results are summarized in Table 3.

Regarding the incentive to the introduction of EE management tools in nationwide freight transportation, the overall objective of the program is to create an EE culture in freight transportation companies. The beneficiary companies of this program and the associated employees were defined as IG for the evaluation.

Regarding the encouragement of improved energy management standards in public transportation companies in Santiago city, the short-term program objective is encouraging the adoption of good practices in the efficient consumption of fuel in public transportation of passengers by developing pilot experiences. However, this program has also a long-term goal, which is the adoption and replication of EE actions in the rest of the public-transportation industry. The beneficiary firms and some non-beneficiary companies of the same sector were defined as IG for evaluation.

Regarding the promotion of efficient driving, the program objective is encouraging the adoption of efficient driving concepts in drivers of road freight vehicles and, in this way, increasing the vehicle performance in the long term. To achieve this goal, the AChEE developed a website (www.conduccioneficiente.cl), which contains multimedia concepts and materials with efficient driving tips depending on the type of vehicle that is driven. Frequent drivers who are users of the website were defined as the IG. In this case, we measure the presence, valuation and mobilizing capacity axes for both the efficient driving program and the use of the website designed for this purpose.

Table 3. Summary of indirect impact evaluation of programs in the transportation sector

Programs	**IG**	**Presence**	**Valuation**	**Mobilizing capacity**
Incentive to the introduction of management tools in EE in freight transportation	Beneficiary companies	N/A	HIGH	HIGH
	Employees of beneficiary companies	MEDIUM	MEDIUM	MEDIUM
Encouragement of improved standards of energy management in public transportation companies in Santiago city	Beneficiary companies	N/A	LOW	LOW
	Not Beneficiary companies	LOW	HIGH	HIGH
Promotion of efficient driving	Frequent drivers / concept of efficient driving	MEDIUM	HIGH	HIGH
	Frequent drivers / usability perceived of the website	MEDIUM	HIGH	HIGH

4.4. Results obtained in the evaluation of programs in commercial, public and residential sector

We evaluated the indirect impacts of two programs in the commercial, public and residential sector. The results are summarized in Table 4.

Regarding the refurbishing of public buildings, the program objective is to promote the implementation of EE measures that contribute to reduce energy consumption in buildings of the public sector, maintaining or improving the level of comfort of the occupants of the building. The program also seeks for validating business models where the generated savings allow financing the investments. The program managers in the beneficiary institutions were defined as the IG.

And regarding the creation of the manager profile in EE and design of the training plan, the program objective is to create an EE manager profile that enables the implementation and maintenance of an EMS of the activities performed by those people involved on the EMS. The IG was defined as individuals trained through this initiative.

Table 4. Summary of indirect impact evaluation of programs in commercial, public and residential sector

Program	**IG**	**Presence**	**Valuation**	**Mobilizing capacity**
Refurbishing of public buildings	Program managers	N/A	HIGH	HIGH
Creation of the manager profile in EE and design of the training plan	Individuals trained	N/A	HIGH	HIGH

4.5. Results of the evaluation of programs in the education and training sector

Table 5. Summary of indirect impact evaluation of programs in education and training sector

Program	IG	Presence	Valuation	Mobilizing capacity
Incorporation of EE in schools and society	Preschool educators	N/A	HIGH	HIGH
	Preschool students	N/A	MEDIUM	N/A
	Preschool staff	HIGH	HIGH	HIGH
	Preschool Parents	MEDIUM	HIGH	N/A
	School educators	N/A	HIGH	HIGH
	School students	N/A	LOW	N/A
	School staff	HIGH	HIGH	HIGH
	School Parents	MEDIUM	MEDIUM	N/A
Research, development and innovation	Project's managers	N/A	HIGH	HIGH
	Project's related companies	LOW	HIGH	N/A

4.6. Results of the evaluation of programs in the measurement and verification sector

In the measurement and verification sector, we only evaluated the indirect impacts of one program: the web platform for registering the electricity consumption in the public sector. The overall objective of this program is to support the monitoring of the energy consumption in public institutions. The users responsible for updating the web platform created for this purpose were defined as the IG. The results are summarized in Table 6.

Table 6. Summary of indirect impact evaluation of programs in the measurement and verification sector

Program	IG	Presence	Valuation	Mobilizing capacity
Web platform for registering the electricity consumption in the public sector	Users responsible for updating platform	LOW	HIGH	HIGH

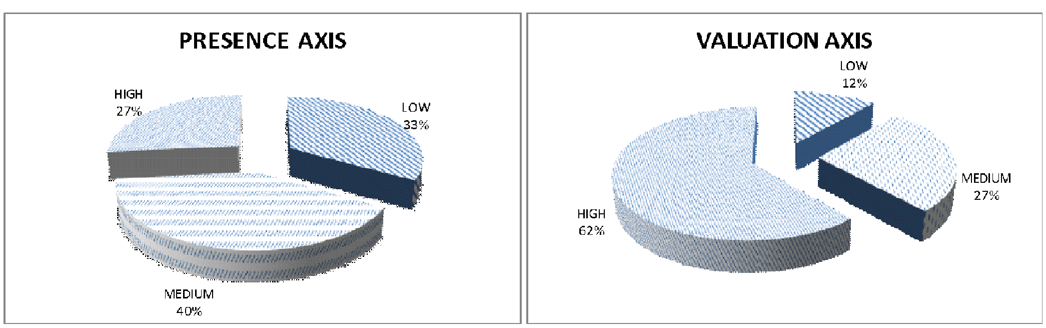
4.7. General discussion

As it can be observed from the results presented, most of the programs implemented by the AChEE have medium or high rating on both the valuation axis and the mobilizing capacity axis, among the different IG considered. However, the presence axis is evaluated at a low level in most cases, which means the EE programs and their subjects are poorly known. This result suggests that there is a serious weakness in the programs and their implementations, especially when considering that cultural changes are needed to achieve large levels of EE outcomes and to promote the internalization and long-term positioning of the EE concept. Accordingly, the results suggest that, in order to truly generate market transformations, it is first required to inform and educate people on the need for a more efficient use of energy.

By applying the proposed methodology, in addition to evaluate the indirect impacts of the EE programs, we detected the presence of some key variables that significantly influence the programs' outcomes. Among these variables, we highlight the recognition of specific profiles of the sectors and population to be targeted by the programs and their cultural, social, economic and educational features. The existence of these variables suggests that the design of EE programs and the definition of their theoretical frameworks must be very carefully analyzed, incorporating these variables and their potential impacts on the results. In this sense, as pointed out by Pelenur (2012), the effectiveness of EE programs can be improved through an interdisciplinary approach to the problem.

It is worth to remark, once again, that the effectiveness of an EE program cannot be only measured by the energy saved for every dollar invested (i.e., the direct impacts) because there are other effects that are very important too. In the past, measuring only the direct impact of programs has led to an overvaluation of programs oriented to equipment replacement. However, investing in EE programs that also have indirect effects is necessary for reaching a long-term market transformation. Such programs, with indirect impacts, create a platform for long-term success of programs with direct impact, which cannot be assigned to a particular program, for one hand, and, on the other hand, they facilitate the incorporation of EE actions without a permanent economic incentive (subsidy) by governments. As pointed out by Blumstein (2010), investing in programs with direct impact and investing in those programs with indirect impact are complementary strategies.

Finally, a summary of the aggregate results of the overall evaluation performed is shown in Fig 5. These results were obtained on the basis of the requirements for each program-IG group, and for each axis of indirect impact levels.



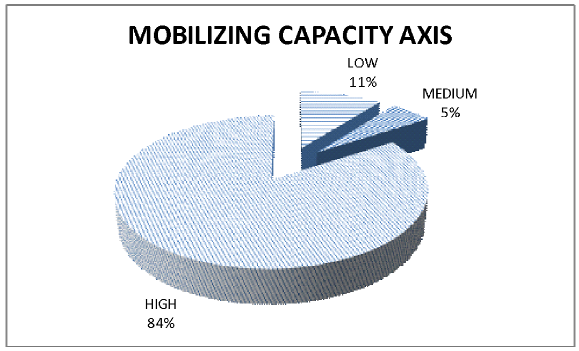


Fig. 5. Aggregate results of the indirect impact evaluation of the AChEE's programs

5. - Conclusions

In this paper, we propose a methodology to assess the impacts of EE programs. The design criteria of the methodology are its applicability to various types of EE programs conducted in developing countries (such as Chile), its flexibility to be applied in a modular manner to either the entire program or parts and projects; and its simplicity.

Current assessment methodologies in the literature and practice focus on direct impacts, which can be quantified and presented under a cost-effectiveness evaluation scheme. Moreover, despite some steps have been taken towards assessing the indirect impacts of EE programs, these methodologies have only focused on identifying these indirect effects or quantifying them in terms of the number of activities done or the number of people attending training or dissemination events.

Although the methodology proposed allows evaluating both direct and indirect impacts of EE programs, in this paper we have focus on measuring the indirect impacts of the EE programs. In order to measure these indirect effects, we use three axes: *Presence, Valuation and Mobilizing capacity*. Contrary to common current methodologies, these axes allow collecting information regarding the people´s levels of knowledge and perception of EE and regarding the usefulness of different EE mechanisms in people's domestic tasks. Accordingly, the definition and evaluation of these axes to measure the perceptions of the IG associated with EE programs is a major contribution in terms of the methodology. This information is essential to move towards transforming markets into more sustainable ones and to generate a suitable base that underpin other EE actions in the long term, which can be quantified in terms of effective energy savings in the future.

The proposed methodology was applied to evaluate the indirect impacts of 12 EE programs, conducted in five different sectors in Chile. As a result of the application of the methodology, the evaluation of the program was determined for each interest group, with respect to three different areas: *Presence*, *Valuation* and *Mobilizing capacity*. In aggregate, the results show a low awareness of the programs and actions by the IGs, and a high valuation and mobilizing capacity of the evaluated programs.

Using this methodology, we were able to detect key variables that influence the effects achieved by the EE programs and that should be considered in its design, implementation and impact evaluation. Cultural, educational and socioeconomic variables are some of these relevant variables. Consequently, the proposed methodology contributes not only to a better assessment of the impacts of EE programs, particularly the indirect impacts, but also to the identification of key variables. Both aspects must be incorporated and evaluated in the programs in order to promote the market transformation needed to incorporate permanent EE actions. This market transformation eventually yields to a reduction of dependence on fossil fuels as a primary energy source (situation of several developing countries) and a reduction of greenhouse gas emissions.

Finally, it is worth noting that an impact evaluation involves the use of both financial and human resources. Accordingly, any institution evaluating their EE programs and projects must have a strategy and plan evaluation, in order to be efficient in the use of these resources and effective in achieving the objectives of the evaluation. In this view, it is important to remark that not necessarily every program should be evaluated.

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2.2 DO DISTRIBUTION COMPANIES LOSE MONEY WITH AN ELECTRICITY FLEXIBLE TARIFF? : A REVIEW OF THE CHILEAN CASE

Do Distribution Companies Lose Money with an Electricity Flexible Tariff ?: A Review of the Chilean Case

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Abstract

We can get an Energy Efficiency (EE) improvement if we produce a flatter daily load curve, leading to a higher efficiency of the power system, making better use of the generation and transport electricity chain, thus avoiding over-investment in equipment used just few hours a year. Tariff flexibility of the Time of Use (TOU) type is one of these measures. Generally, TOU systems are designed to minimize total system cost, which may cause losses in distribution companies (DISCOs), generating opposition. On the contrary, the present paper proposes a TOU system for electricity consumption in Chile where optimal prices are obtained in order to maximize total income of DISCOs. In this manner, the proposed TOU system is, by definition, beneficial for DISCOs and it may lead to a win-win situation among DISCOs and consumers. In particular, we show that such a system, implemented in a country like Chile, would allow for DISCOs a total potential benefit of 811.7 millions of dollars for the 3-year study period (2005 to 2007), considering initiatives that promote a 5% savings in real consumption during on-peak

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hours, obtained by the spread or difference between the proposed and the current systems.

Key words: Tariff flexibility, Time of Use, Energy Efficiency, flexible pricing system, load curve.

JEL Classification: D42 - D61 - L11 - L94

1. INTRODUCTION

Currently, an ongoing debate is underway in many countries regarding the sources of energy, their generation and use. The sustained increase in global demand for electricity, its direct relationship with countries' economic development, the cost of generating and the impact on the environment that power generation produces, have shown the need to take actions that allow to optimize its use. There are various measures that can be implemented to achieve this goal, some of which are intended to influence the behavior of the end users of electricity, and that could be channeled through the electricity distribution industry. In this way, the debate at the global level has also focused on the design of regulatory mechanisms that encourage distribution companies (DISCOs) to implement energy efficiency (EE) programs. This because they do not have economic incentives to incorporate EE programs to help their consumers to be more efficient in the use of energy if the programs translate into a decrease in sales and income. However, it must be taken into account that the effects of these measures depend on price elasticities, which can vary considerably between one industry and another [1].

Along the same line of thought, [1-7] point out the possibility of having a rebound effect. So, while the expected effect should be a rational decrease in energy consumption, in opposite, the increases in technology efficiency from the energy point of view may determine an increase in global energy consumption because of larger aggregate consumption demand [1-7]. As Herring [8] points out: "Advocates of energy efficiency acknowledge that some of the savings from efficiency improvements will be taken in the form of higher energy consumption—the so called 'take-back' or 'rebound' effect. However, there is still intense dispute about its magnitude. It is strongly argued that it is much less than 100%; perhaps in the order of 10–20%."

As well, Laitner [9] states: "Depending on the assumptions of income and price elasticities, as well as the supply/demand interactions within a macroeconomic model, the rebound effect might reduce overall savings by about 2 to 3% compared to a pure engineering analysis. In other words, an economy-wide, cost-effective engineering savings of 30% might turn out to be only a 29% savings from a macroeconomic perspective. Despite the impact of a rebound effect, the net result of energy efficiency policies can be a highly positive one."

Today, the majority of residential consumers of electricity in developing countries are offered a service with a flat tariff scheme, based on the average cost of providing the service. This system does not provide such customers with incentives to modify their pattern of consumption in periods when the cost of producing the electricity rises [10,11]. Thus, demand responsiveness to the information on prices, a critical variable to the proper functioning of markets, is not present in the majority of these energy markets. In contrast, a flexible pricing mechanism is capable of generating such a decrease in the variability of consumption levels among hourly segments during the day, which in turn reduces uncertainty and variability of electricity costs [12]. Thus, flexible pricing offers opportunities to reduce the electricity supply costs and the risk of not satisfying the demand for electricity. In this way, the design of a suitable system of flexible tariff can help to operate a smart grid [13].

Flexible pricing has been implemented generally for large consumers (commercial and industrial). A good example of this is the Georgia Power program, in which more than 1,600 of these large consumers face different hourly rates and where close to 850 MW in power demand reduction have been verified [14]. In the case of Chile, Mendez [15] points out the importance of having an efficient pricing system of electrical energy for users in order to send the right signals to the market to make the expansion of transmission lines and the construction of new power generation more efficient within a competitive market.

Generally, TOU systems are designed to minimize total system cost, which may cause losses in DISCOs, generating opposition. On the contrary, the present paper proposes a TOU system for electricity consumption in Chile where optimal prices are obtained in order to maximize total income of DISCOs. In this manner, the proposed TOU system is, by definition, beneficial for DISCOs and it may lead to a win-win situation among DISCOs and consumers.

This paper investigates the results of the design of a flexible pricing system (of the Time of Use, TOU, type) for electricity consumption in Chile, where an optimal pricing model for electricity consumption has been determined by means of price-consumption elasticities, in such way that, for each simulated scenario of the response of users associated with such node, there exists an indicator that shows the price-consumption sensitivity in each price scheme. Thus, we measured the effect of the application of a flexible pricing system (of the TOU type), with optimal prices defined using the elasticities, which would induce the desired behavior in the end consumer of electricity in a way that the consumption and electricity prices can reflect more closely the risk associated with the power generation cost; achieving greater efficiency of the electrical system without affecting the profit earned by the DISCOs. We model the response of the demand and the DISCOs' objective following this rationale.

2. "TIME OF USE" (TOU) PRICING SYSTEM

There are several systems of electricity pricing in the world. Some are fixed, where there is a flat fee regardless of the load curve and the time of consumption (which corresponds to the current Chilean model for residential customers), and some are flexible, whose rate is differentiated on a temporal basis [16]. Within these latter ones, are included the Time of Use (TOU) Pricing, Critical Peak Pricing (CPP), and Real-Time Pricing (RTP), which have been detailed by several authors [17-20].

In the specific case of TOU system, both prices and periods of application are known a priori and fixed to some length, typically a season [21]. However, and although the TOU system has different rates for each defined block, these rates do not consider the times of saturation or demand peak of the system and do not capture variations in demand and costs of operation in real time. i.e., uses just one price for the same periods of time, regardless of the status of load on the system or wholesale prices. On the other hand, to try to reflect seasonal variations, a readjustment of prices and/or the duration of the blocks is performed two or three times a year. Faruqui and Malko [19] presented the results of twenty experiences of TOU systems allowing concluding that:

1. TOU pricing system reduces the consumption in peak periods, however in average or low consumption periods it remains constant or increases in small quantities.
2. A change in the load curve is rarely observed and the TOU system prices cause an overall decrease in the daily consumption.
3. Users who demand power in on-peak periods are more price sensitive than those who do so in off-peak periods.
4. Elasticities for on-peak and off-peak periods vary in a range of 0 to - 0.4. These differences in the variations are explained by the various climates, prices and consumption used for the study.

On the other hand, if implementation of the TOU system considered the voluntary association of customers to the program, a problem could arise in the achievement of the improvement objectives of the proposed EE measures, as in this case only those customers who obtain savings related to an overall decrease in consumption or generate one block tariff to another transfer would subscribe to this pricing scheme. This situation may generate a loss of income for the DISCOs due to lower sales associated with consumers who subscribed to the plan; and in that context, these companies will seek to remedy such loss increasing the rates of those consumers not hosting the program, thus determining a zero sum game insofar as the savings achieved in the global system [22].

Therefore, to address the problem of flexible electricity consumption pricing, there should be a consideration of the impacts on two important variables: the revenue earned by electric power distribution companies and the response or variation in consumption response of users to the new pricing system of electricity. To combine both effects may generate a win-win strategy, benefiting both companies and end-users.

3. MODEL OF FLEXIBLE PRICING TOU TYPE ADAPTED TO THE CHILEAN CASE.

3.1 Background information.

The proposed flexible pricing model is applied to the main Chilean electric system, SIC, which covers the majority of the energy consumption of the country. In Chile, energy and power prices for large consumers (with a level of consumption over 2,000 kW) are determined by bilateral agreements between parts. However, in the case of energy supply to end- users whose connected power is less than or equal to 2,000 kW, the price is established by regulation law. Thus, customers that make up this market segment are called regulated customers.

For regulated customers, the Chilean electricity law distinguishes prices at generation, transmission, and distribution levels. The latter prices are determined as a value added per concept of distribution operations and a charge for using the grid. The generating companies can sell their energy and power both in the large consumer market, where the price of the transaction is agreed freely; and also, in the market of the DISCOs, where the price is regulated based on a "nodal pricing". The price that the DISCOs can charge to regulated customers located in their area of distribution, for the distribution of electricity service, is given by the following expression:

$$P_f = P_n + TCG + AVD \tag{1}$$

where:

P_f : End-user price

P_n : Regulated nodal price

TCG : Toll charge for grid use

AVD : Added value of distribution

While nodal prices are commonly set by market competition, in Chile they are regulated by law. Accordingly, Chilean “nodal prices” are set twice a year, in the months of April and October of each year. These regulated nodal prices have two components: the first, called basic price of energy, which corresponds to the average in the time of the marginal costs of energy from the electric system, operating at the minimum updated cost of operation and rationing, during the period of study; and the second, called the basic price of the peak power, which corresponds to the annual marginal cost of increasing the installed capacity of the electrical system considering the cheaper generating units, determined to provide additional power during the electrical system’s peak demand hours of the year, increased by a percentage equal to the theoretical power reserve margin of the electrical system.

For each one of the nodes of the electrical system, energy and power-related penalty factors are calculated, that multiplied by the respective basic price of energy and peak power determines the price of energy and power in the respective node. On the other hand, the Added Value of Distribution, AVD, is set every four years by the Ministry of Economy, Development and Reconstruction, and corresponds to an average cost that includes all the investment and operation costs of a theoretically efficient business enterprise operating model in the country, with an efficient investment policy and management. However the AVD does not necessarily recognize the costs actually incurred by the DISCOs.

Thus, rates that finally face regulated distributors clients consist of prices of generation, transmission, and added values by distribution costs. Generation prices correspond to the regulated nodal prices determined semi-annually; prices of transmission component corresponds to the toll for the use of backbone transmission facilities; and finally the component distribution, corresponding to the AVD, which represents the payment to the company distributor of their cost of investment, operation and maintenance, losses, and expenses of administration, billing and customer care.

3.2. Model assumptions.

The flexible pricing model to be proposed seeks to implement a rating system, where the residential end-users of energy (regulated clients, in the Chilean case), assume a larger cost if their main daytime energy consumption takes place in slots of congestion or larger aggregate consumption of the system. Thus, economic incentives are generated for users to reduce or "move" consumption in congestion (on-peak demand) sections to stretch medium or low level consumption, making them sensitive to higher costs of generation, transmission and distribution in on-peak schedule.

Mathematically, and as an assumption for the tractability of this model, the SIC’s system of nodes complies with the properties of set covering and set packing, by which all tariff solutions comply with the condition of set partitioning and therefore, the optimal rate of the system will be the sum of the best of the partition. Given this configuration, the model will work in a first phase on the basis of a particular node, to generalize the analysis later, to the rest of the selected nodes and to the whole SIC system.

To analyze the income received by the DISCOs and the variation in the form and schedules of customer’s consumption, there will be a comparison of these variables between the current scenario and the scenario with the proposed scheme. The model will consider the implementation of a flexible hourly charging system comprised by three daily tariff segments (on peak, middle peak and off peak), characteristic of each node. Thus, for each of the nodes that make up the SIC, analysis of their profile of time consumption and the marginal costs of generation associated with that profile will be carried out. On the other hand, as a measure of customers’ consumption sensitivity is not available to variations in the price of electricity, to simulate their response to changes in pricing, we generate different scenarios representing the variation of customers’ consumption.

Therefore, each scenario will be a simulation of a possible “turnover” of consumption between each time segment. Thus a study of the current pattern of customer consumption response will be possible for each schedule section, with its corresponding duration and price, in the face of variations in pricing of energy. This model assumes that each node of the SIC reflects the consumption characteristic of the zone in which is located, so that the behavior and consumption of each node may give an account of the behavior of customer consumption in that geographical area. In addition, in this comparative analysis both competing schemes charging periods will be compared during October-April period of each year of study, not only to realize the effect of daily and hourly variations in consumption in certain segments, but also of those variations that are a product of seasonality.

Assuming that eventually there may be energy transfers among different nodes of the SIC, there applies the idea of risk polling[9], which for the purposes of this model, is considered marginal to the distorting effect of possible transfers of energy on the pattern of overall consumption of the system's clients. On the other hand, the variations in price of each segment will be determined, as a measure of sensitivity, establishing a role of consumption-cost elasticity characteristic of each node, so that, for each user's response to prices scenario differentiated by segments, there will be an indicator to show sensitivity in each consumption-cost associated to a schedule section. It should be noted that for each simulated scenario, there is a characteristic consumption per node, which directly determines the role of elasticity price-consumption in the specific time segment. This function is therefore built by comparing the consumption of each node in each fare segment, with the price level of electricity in this segment.

3.3 The model.

The model used in this study can be described as a methodology of seven steps, each of which was applied to all nodes in the main Chilean interconnected power system, SIC. Each of these steps is detailed below. In order to illustrate the implementation over the

9 Risk pooling is an important concept in the management of the supply chain, which suggests that the variability of demand is low considering the aggregate demand, because the aggregation occurs in different locations. Thus, by introducing inter-decadal with different backgrounds, the effect on aggregate demand is minimized. For further reference see [23].

nodes of the specific step that has been detailed, we use a prototype node (called *Pan de Azucar*). This is made only to explicit the description of the methodological procedure. Figure 3 shows a schematic picture of the whole methodology used here.

Step1: Obtaining and validating data.

For each node belonging to the main Chilean interconnected power system (from now onwards SIC), data regarding both consumption characteristics of each bar and the marginal generation costs associated with that consumption pattern, were collected for the years 2005, 2006 and 2007. The information was obtained from the Center for Economic Load Dispatch of the SIC, CDEC-SIC, and from the Chilean National Energy Commission, CNE.[24-27]
The information collected was inspected and validated, because in some cases exhibited abnormalities (e.g., negative consumption values), which were excluded from the database.

Step 2: Selecting Nodes

Once validated information was available, we selected those nodes of the SIC that had enough information about marginal costs and consumption characteristics of the bars associated to such nodes. Specifically, the criteria for selection of these nodes were two: (i) that they belong to the backbone of the SIC (main nodes), and (ii) that the node has available information regarding the extent of consumption and the marginal costs of the energy in each tariff segment (the latter being needed to quantify the income variation of the DISCOs as a result of the application of the model). To analyze the system, 22 representative nodes of the SIC were chosen. The 22 nodes selected are: Quillota, Carrera Pinto, Valdivia, Los Vilos, Itahue, Rancagua, Huasco, Polpaico, Las Vegas, Paine, Puerto Montt, Punta cortes, Cardones, Pan de Azúcar, Charrua, Rapel, Chillan, San Fernando, Cholguan, San Vicente, Concepcion, and Temuco.

Figures 1 and 2 show the daily average marginal costs and energy consumption during the years 2005-2007, for the Pan de Azúcar node (prototype node). These figures reveal the existence of low, medium and high levels of power consumption and marginal cost throughout the day, suggesting the use of a flexible pricing to generate a more bounded behavior of electricity demand for certain critical costs and consumption segments.

Figure 1

Daily Average Marginal Costs of the Prototype Node

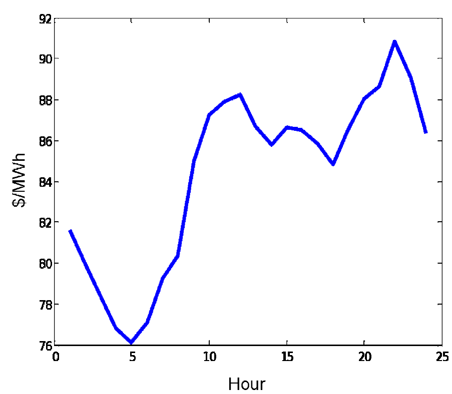
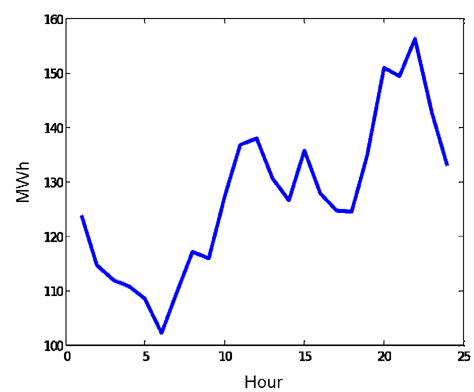


Figure 2

Prototype Node Characteristic Average Consumption



Step 3: Generation of base case

For each of the 22 selected nodes, the payment of the DISCOs to the generation firms (expenditures) and the profits of the DISCOs were determined in the base case, corresponding to the current pricing system (fixed-tariff system), during the analysis period, 2005-2007.

i. Payment of the DISCOs to the generation firms in the base case.

The payments of the DISCOs to the generation firms in the fixed charging system (base case) are determined. For this, the consumption at each node selected is multiplied by the regulated nodal price of electricity. Recalling the regulated nodal price is updated biannually in April and October of each year, to account for variations in cost and consumption due to seasonality and other factors. Therefore, for the period of study, a vector of nodal prices was generated, whose weighted vector of consumption times price on the relevant dates delivers a proxy indicator to the expenditures of the DISCOs with the current pricing system, which will be subsequently compared with the results of the application of the flexible charging system.

ii. Determination of profits of the DISCOs for the base case.

On the other hand, DISCOs' profits are obtained by multiplying nodal consumption and the corresponding added value of distribution (AVD), corresponding to the period 2004-2007. It should be noted that this mechanism leads to the profits of the DISCOs being linked to their level of sales of electricity, which becomes an obstacle to the successful application of differentiated pricing sections, to induce a net decrease of electricity consumption at the residential level and the consequent adverse impact on the economic interests of these companies.

Step 4: Generation of an optimal combination of hourly blocks and rates per node.

To establish a three-segment flexible pricing system, we sought the optimal combination of time segments for each selected node. The desired goal was to maximize the revenue of DISCOs, given the characteristic behaviors of each bar consumption, the cost-based power rating existing in Chile, and subject to the constraint that each time segment has a minimum duration of three hours.

The revenue of the DISCO was computed by multiplying the characteristic consumption and the rate for each tariff block. Accordingly, it is necessary to establish, for each node, the optimal duration and the rates for each tariff block.

i. Rates for each tariff block

A reference price is obtained for each tested rate segment (On peak, Middle peak and Off peak), which is calculated by applying a commercialization margin to the average cost of this segment (which for this study was considered 10%). The average cost, for each time block of each assignment, is obtained as the average of the costs in the pricing section. Thus, the unit selling price corresponds to:

$$P_{s(i,j)} = C_{av(i,j)} * (1 + M_d) \tag{2}$$

where:

$P_{s\ (i,j)}$: Price of tariff segment *i* in the combination *j* of time segments

$C_{av\ (i,j)}$: Average cost of tariff segment *i* in the combination *j* of time segments

M_d : Margin of commercialization

The idea of using a commercialization margin on the cost environment, rather than using the final price to the consumer of electricity, is to measure the impact of variations in consumption on the variations of marginal costs and these variations in the final price to the consumer. In this way, the variation of the final price will be a function of consumption and not the value added of distribution variation and/or tolls of the core system.

ii. Duration of segments of each tariff block

The income of the DISCO is calculated by: multiplying the price of the corresponding segment and the hourly consumption of each segment, for each tested rate segment, and summing up over all the segments, subject to the constraint that there is a minimum duration of 3 hours per segment. That is,

$$I_d(j) = \sum_{i=1}^{N} P_{s(i,j)} * (\sum_{h=1}^{D} C_{(i,j)}) \qquad (3)$$

where:

$I_d\,(j)$	:	Income of DISCOs with the j combination of tariff blocks
N	:	Number of daily segments
D	:	Duration of segment i
$P_{s(i,j)}$	:	Price of tariff segment i in the combination j of time segments
$C_{(i,h)}$	:	Consumption in the tariff section i which has a period of h hours ($h \geq 3$).

That is, the income of the DISCO, with the tariff blocks j combination, shall be equal to the sum of products of prices in the segment i allocation j, times the sum of consumption in the tariff section i which has a period of h hours ($h \geq 3$). [10]

Finally, we choose the hourly tariff blocks combination that maximizes the income of the DISCOs, given the new scenario of prices per block. For example, for the prototype node, three tariff blocks were optimally determined, which start at hours h = 0, h = 9 and h = 19.

Step 5: Generating a function of sensitivity Consumption – Price for each node

[10] The minimum duration of 3 hours for any block tariff was chosen for simplicity reasons and for realism of practical implementation of this pricing system.

For each node and optimal tariff segment, a consumption-price sensitivity function was generated, as a proxy to the sensitivity of the consumption of the respective bar, with respect to changes in prices generated from transfers (to be simulated in this model) among blocks with different tariffs. The idea is to obtain bounds on the effects that could be set on consumption in each simulation of energy transfers among tariff blocks and, therefore, determine the energy savings and the effect on revenue of DISCOs.

This sensitivity function was generated from the analysis of daily consumption during the years 2005 to 2007, ranked by every consumption segment (Off Peak, Middle Peak and On Peak), using the least squares method to establish a linear relationship between price and consumption for the seasonal periods included in the horizon. This yields an index of consumption-price sensitivity for each of the time segments (Off Peak, Middle Peak and On Peak) for the period from October to April and for the period from April to October (A total of six values for each one of the 22 nodes).

Step 6: Determination of payment for power savings

For each node under analysis, it is necessary to compare the changes in the revenue of the DISCO produced by potential savings to be gained by the decline of investment in generation capacity, due to the change in the customers pattern of consumption, so as to evaluate if the whole system is more efficient from the energy point of view when reducing the variability of daily consumption. To achieve this comparison, it is necessary to create a proxy indicator to account for the payments for capacity and energy, which DISCOs pay for to the generators, as a way to estimate the savings associated to the peak demand reductions. This proxy indicator will be built as the average value of capacity payments in the study period so that, for every MW decreased during the peak working hours, there is a proportional payment to this drop in consumption. To be able to quantify the potential savings to the system, as a result of decreases in consumption at peak times, reference capacity payments in the Chilean SIC market were considered, contained in the October 2007 nodal price report [26]. In addition, a vector of capacity payments was obtained corresponding to the periods October 2004 to April 2007, which was weighted by the savings simulated between hourly tariff segments of the node in analysis. Therefore, for each simulated variation of consumption between hourly slots, there will be a characteristic savings capacity value.

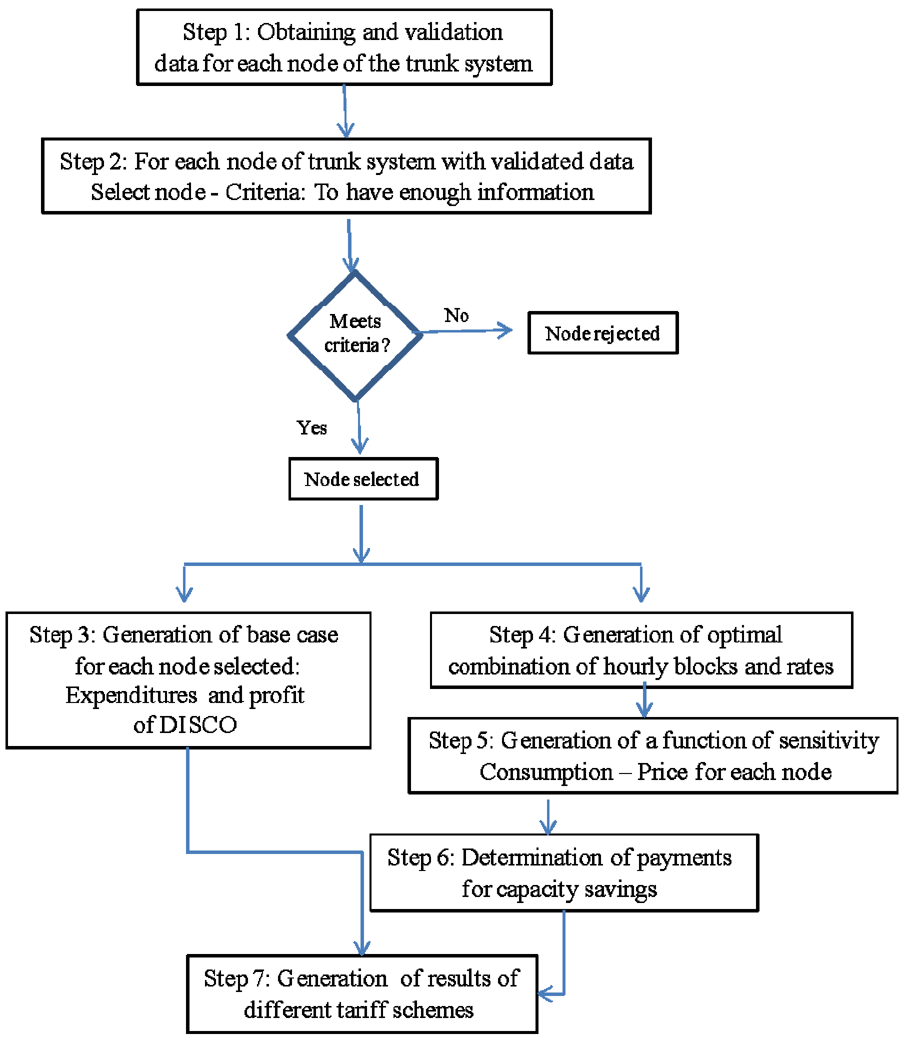
To quantify the simulated power savings in this exercise, a scenario of change for each node is defined. This scenario is characterized by inducing percentage variations in the behavior of consumers, from increased consumption to lower consumption segments, successively. The idea behind this structuring of scenarios is to account for users' different sensitivities depending on the season in analysis. Users are less sensitive (in their behavior) to price in the April-October period than in the October-April period, because of the winter cold and the lesser amount of light in this day period. Thus, for instance, for the prototype node, we simulate a scenario where there is a 10% transfer in the nodal consumption from on-peak segment to middle-peak segment and a 10% transfer from middle-peak segment to off-peak segment, as a result of the implementation of the new tariff.

Step 7: Generation of results of different tariff schemes

With the information generated in the above steps, for each selected node it was determined: the payments that consumers make to DISCOs under the flexible pricing scheme, the payments that DISCOs make to generators for the energy provided, the profits of DISCO in both the base case and in the case of flexible pricing and the spread between the two systems, considering also the savings in power capacity.

These calculations were performed considering two flexible pricing schemes: one called the asymmetric case, where the price paid by end-consumer varies by segment, but the price that DISCOs perceive is maintained under a fixed schedule, and another scheme called the symmetric case, where consumers and distribution companies face different prices per segments. In the case of the prototype node, the results obtained are shown in the next section.

Figure 3: Methodology of the model



4. RESULTS OBTAINED IN THE PROTOTYPE NODE

The overall results for the prototype node, where different charging mechanisms are compared through the access of the distributors, are shown in Table 1.

Table 1: Comparison of utilities with flexible pricing model and profit under current model for prototype node: 2005-2007 period. (Asymmetric case)

	Results for the prototype node	Million $
A	**Payment made by consumers to the distributors, under the flexible pricing scheme** (Price tariff blocks*Consumption in blocks)	365.66
B	**Payment of the distributors to the generators** (Nodal Price* Consumption in blocks)	335.9
C	**Utilities of distributors, under the flexible pricing scheme** (A-B)	29.76
D	**Profit under current model for node model** (AVD* Consumption in blocks)	11.62
E	**Spread** (C-D+ Saving for payment power)	18.67

Table 1 shows that the payment made by consumers to the distributors, under the flexible pricing scheme ($365.66 million), is larger than the payment of the distributors to the generators ($335.9 million). This difference is a proxy for added value distribution plus tolls per use of the backbone transmission system. On the other hand, the utility obtained by DISCOs is superior in the scheme of flexible pricing than in the base case, with a constant energy price, only updated by seasonality (winter & summer rates) factor, thereby creating a positive spread of flexible pricing in relation to fixed (current) charging pricing. The explanation of this behavior lies in the shape of the node's curve and the simulated scenario consumption (10% transfer of energy consumption among on-peak, middle-peak and off-peak hours, respectively). This situation determines that benefits of the pricing scheme vary from node to node.

Now, if the effect of the consumption variability is not only absorbed by the distribution company, but it is also "transferred" to the whole electricity supply chain, this creates a communication link between the final consumers of energy and the generators. In this way, if there are variations in the costs of generation caused by different reasons (such as a possible period of drought, increases in cost of fuels and other inputs of the power generation process chain, or problems of a contractual nature and/or dispatching), it will be quickly reflected in the amount of energy consumed by the regulated customers. There are several ways to convey the sensitivity of consumption, one of them is through the current setting of a fixed nodal price, which collects the variability, but with a lead time or gap of almost 6 months. Another way is the generation of a nodal price which is differentiated by time, similar to the flexible pricing scheme previously mentioned, where different slots with a different price/charge each, is faced by end users. A hypothetical situation in which there could be a symmetrical flexible pricing on "both sides of the distribution chain", that is where there is a flexible pricing to consumers to the distributors, and these in turn have a flexible payment scheme based on the latter to the generators, and where each node could be charged differently according to a defined pattern of consumption, would give the following results:

Table 2: Comparison of utilities and profits under flexible pricing model and transmitting the variability of electricity consumption supply chain for node model: 2005-2007 period. (Symmetric case)

	Results for the prototype node	Million $
A	**Payment made by consumers to the distributors, under the flexible pricing scheme** (Price tariff blocks)*Consumption in blocks	365.66
B	**Payment of the distributors to the generators, under the flexible pricing scheme** (Gen. Price tariff blocks)*DISCOs use in blocks	329.09
C	**Utilities of distributors with flexible pricing model** (A-B)	36.57
D	**Profit under current model for node model** (AVD* Consumption in blocks)	11.62
E	**Spread** (C-D+ Saving for payment power)	25.48

Table 2 shows an increase of 6.81 millions of dollars between different pricing models for the system, by effect of transmitting the variability of electricity consumption supply chain, considering the 2005-2007 period. This is explained by the typical consumption pattern in the node; reason why, this greater bonanza for effect of flexible pricing that is transferred to the supply chain, can vary from node to node.

5. RESULTS OBTAINED IN THE GENERAL APPLICATION OF THE MODEL

The procedure described above was applied to a set of 22 nodes of the central interconnected system (SIC). The selection criteria of the nodes that will work to generalize the result are belonging to the core/backbone system and the adequacy of the marginal costs and consumptions data in the study period. These nodes,[11] as a whole,

[11] Nodes considered in the analysis are: Quillota, C.Pinto, Valdivia, Los Vilos, Itahue, Rancagua, Huasco, Polpaico, Las Vegas, Paine, P. Montt, Punta cortes, Cardones, Pan de Azúcar, Charrua, Rapel, Chillan, San Fernando, Cholguan, San Vicente, Concepción, and Temuco.

represent 27,714.42 GWh of electric power consumption and 64.15% of the total energy consumption of the SIC which corresponds to 43,198.70 GWh. Given this representation of the system, a scale factor of 1.6 was generated for the entire SIC which accounts for the fraction of energy considered in the study, within the total and which will amplify the results obtained in the implementation of the entire model, considering that the system involved behaves in a manner similar to the sample selected, with respect to their costs and consumptions.

Furthermore it was considered that the annual savings/dissaving obtained annually due to the variation in the pricing of electricity consumption, constituted under conceptual and academic assumptions, a perpetual annuity, by which corrected to a discount rate of 8%, the present value of the change in the pricing model is obtained.

It was also considered in this extension of the pricing model, that the variability of consumption, expressed in income variability of distributors, is transmitted throughout the entire chain of electrical supply, i.e., that both the payment of end consumers to DISCOs as well as payments of these companies to power generation and transmission is differentiated into three tariff slots triggering a nodal price differentiated for the three slots and dependent on the geographic area; a case referred to as symmetric pricing.

The results obtained from the general application of the model of flexible pricing applied to the Chilean case, for the symmetric charging scheme, are illustrated in Table 3, where the spread of the charging system in relation to the present case, has been grouped according to the minimum percentage savings for the winter and summer periods.

Table 3: Characteristic values of the spread in symmetric case.

The formation of prices by block in April 2005 is function of marginal costs project in this period, in which the marginal costs in the middle schedule were larger than the peak schedule marginal costs.

	Savings % Summer									
Savings % Winter	5%	10%	15%	20%	25%	39%	35%	40%	45%	50%
5%	811.7	816.5	821.3	826.2	831.0	835.8	840.6	845.4	850.2	855.0
10%	815.0	819.8	824.6	829.5	834.3	839.1	843.9	848.7	853.5	858.3
15%	818.3	823.1	828.0	832.8	837.6	842.4	847.2	852.0	856.8	861.6
20%	821.6	826.4	831.3	836.1	840.9	845.7	850.5	855.3	860.1	864.9
25%	824.9	829.7	834.6	839.4	844.2	849.0	853.8	858.6	863.4	868.3
30%	828.2	833.1	837.9	842.7	847.5	852.3	857.1	861.9	866.7	871.6
35%	831.5	836.4	841.2	846.0	850.8	855.6	860.4	865.2	870.0	874.9
40%	834.8	839.7	844.5	849.3	854.1	858.9	863.7	868.5	873.4	878.2
45%	838.2	843.0	847.8	852.6	857.4	862.2	867.0	871.8	876.7	881.5
50%	841.5	846.3	851.1	855.9	860.7	865.5	870.3	875.2	880.0	884.8

The generalization of the results in the application of the model of symmetrical pricing has several consequences, among them we can mention:

1. The total absorption of the variability of consumption allows the behavior of end users to influence the structure cost of the generating companies, across levels of consumption. In turn, the variability in the cost structure of the generating companies influences the consumption behavior of end users, through the price of energy in the different hourly slots. That is you get a mutual influence among the different players who participate in the system.
2. Electricity supply chain communication is performed through the price of it, the costs of generation and levels and forms of end users consumption. This translates into the variability of costs, both seasonal and daily, which have an impact on the price paid by end users for the electrical energy. With this scheme then, it is not necessary to wait 6 months to fully internalize in the changes the price produces in the behavior of customers consumption, which allows that the users' response to the variation in prices be absolutely consistent with the structure and evolution of the costs of generation.

3. The necessary savings effort on peak demand slots is marginal, in relation to the base case (current pricing system) if one wishes that symmetric pricing allows for a change in the pattern of consumption of users in this period, and at the same time, generate a positive spread on the income of the DISCOs. In fact, symmetric pricing allows us to obtain a positive spread almost independently of the level of response of the end users. Empirically it is possible to reflect this situation through the next mantle of relations:

The mathematical relationship between percentage savings and the spread of pricing systems, for the symmetric case, is given by:

$$S_{ps} = 803.57 + 66.18 * W_s + 96.3 * S_s \qquad (4)$$

where:

S_{ps} : Spread of pricing system

W_s : Percentage of winter savings

S_s : Percentage of summer savings

In (4), the coefficients of the percentage savings in winter and summer seasons represent the elasticity spread v/s percentage of savings. Given the values of these coefficients, you can see that the sensitivity of the users is lower in the winter period. On the other hand, the mantle of solutions that allow to establish a win-win situation, in which the minimum necessary savings in summer and winter to achieve a change in the pattern of consumption of users is expressed, and at the same time, a positive spread between pricing systems, exhibit the following relationship:

$$-803.57 = 66.18 * W_s + 96.3 * S_s \qquad (5)$$

Where:

W_s : Percentage of winter savings

S_s : Percentage of summer savings

This mantle of solutions explicitly shows that the minimum necessary savings for the symmetric pricing system to have a positive spread must be negative, implying that for any level of savings from the peak demand hourly slot to a medium level, the system manages significant benefits in relation to the base case (Some characteristic values of the equation (5) are given in Table 3).

From the symmetrical flexible tariff model applied to the Chilean SIC we can obtain the following results:

i. Considering initiatives that promote a 5% savings in real consumption during on-peak hours, during both winter and summer, the spread or difference between the proposed and the current systems is of $811,7 millions in the 3-year study period. Considering an annual discount rate of 8%, we obtain that the profit for DISCOs of implementing the proposed flexible tariff system with three price segments is $3,260 million.

ii. The spread obtained by DISCOs under the two tariff schemes is affected by the percentage of consumption savings in a different manner during winter and summer. Equation (5) provides the details of the corresponding factors. Accordingly, for example, under a 1% variation in the consumption savings during summer, the impact in the spread is of $0.96 million instead of the $0.66 millions observed during winter.

iii. In order to produce an additional benefit of $43.3 million in the spread, both are needed an effort in consumption savings equivalent to transfer 45% of the on-peak consumption to the medium-peak block during summer and an effort in consumption savings equivalent to transfer 5% during winter.

iv. The spread variation among winter and summer corresponds to a difference of 9% for values of energy consumption savings; in a range of 5% to 50%. This represents an upper bound of the effects expected when implementing the proposed pricing scheme.

v. If we only consider the energy consumption change from on-peak blocks to medium-peak blocks, the critical percentage that allows the symmetric flexible tariff system to have a positive spread is negative. This gives a positive lower bound of the expected profit for DISCOs of implementing the proposed pricing scheme; and this occurs for any level of energy consumption transfer from on-peak to medium-peak blocks.

6. CONCLUSIONS

This work have established the potential benefits of having a TOU system for electricity consumption where optimal prices are obtained in order to maximize total income of DISCOs, as opposite to minimize total system cost. We show that the proposed TOU system may lead to a win-win situation among DISCOs and consumers.

To show this, we simulated alternative scenarios representing feasible responses by consumers when facing variations in the energy pricing scheme. The results show that it is possible to incentivize DISCOs in order to incorporate flexible tariff schemes, but that the intensity of the incentive depend on the consumption profile of the considered nodes. Given this situation, as future work, it would be interesting the development of a flexible tariff pilot project that considers some representative nodes of the SIC and empirically measures the regulated consumers' response when facing a variation in the energy pricing scheme. Such variations should not only consider the resulting prices coming from the consumption profiles at every node, but also the seasonality and the hourly congestion blocks. In such a way, it could be feasible quantify the sensitivity of the consumers' response, the consumption transfers among time blocks, the impact over DISCOs' income and the aggregate effect over the system efficiency.

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APPENDIX

Price, consumptions and costs for prototype node, Pan de Azucar, with a flexible tariff model

Price by block for prototype node ($/MWh) Schedules between 9 and 19 hours			
Period/Block	**Off peak**	**Middle peak**	**On peak**
Oct-04	84.90	93.15	96.23
Apr-05	36.98	44.56	43.85[a]
Oct-05	35.00	39.70	40.23
Apr-06	104.99	93.32	101.23
Oct-06	75.65	89.11	89.13
Apr-07	128.13	146.87	148.18
Oct-07	170.39	190.39	193.58

[a]: The formation of prices by block in April 2005 is function of marginal costs project in this period, in which the marginal costs in the middle schedule were larger than the peak schedule marginal costs.

Consumption by block for prototype node (MWh)			
Period/Block	**Off peak**	**Middle peak**	**On peak**
Oct-04	30.38	35.62	40.15
Apr-05	30.00	31.41	33.44
Oct-05	29.40	35.35	40.96
Apr-06	165.31	190.26	220.56
Oct-06	234.96	269.11	289.42
Apr-07	136.52	160.61	185.31
Oct-07	119.51	144.48	160.56

Costs by Block for the prototype node ($/MWh)			
Period/Block	**Off peak**	**Middle peak**	**On peak**
Oct-04	77.18	84.68	87.48
Apr-05	33.62	40.51	39.87
Oct-05	31.82	36.09	36.58
Apr-06	95.44	84.83	92.03
Oct-06	68.77	81.01	81.03
Apr-07	116.49	133.52	134.71
Oct-07	154.90	173.08	175.99

2.3 DOES A CARBON TAX MAKE SENSE IN COUNTRIES WITH STILL A HIGH POTENTIAL FOR ENERGY EFFICIENCY? COMPARISON BETWEEN THE REDUCING-EMISSIONS EFFECTS OF CARBON TAX AND ENERGY EFFICIENCY MEASURES IN THE CHILEAN CASE.

Does a carbon tax make sense in countries with still a high potential for energy efficiency? Comparison between the reducing-emissions effects of carbon tax and energy efficiency measures in the Chilean case.

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Abstract

Many countries have not yet successfully decoupled their growth and their energy consumption. Moreover, energy production frequently entails a number of negative externalities, like greenhouse gas emissions from thermo electrical units. This situation has highlighted the need for countries to move towards sustainable economic growth. Accordingly, many countries have proposed and established measures to decrease their carbon emissions. In this line, the Chilean government has just passed a carbon tax of 5$/Ton CO_2e. In this work, we compare the effectiveness on reducing CO_2 emissions of this carbon tax and of some energy efficiency measures in the power sector. The results obtained indicate that the imposed carbon tax will produce an expected annual reduction in CO_2 emissions of 1% with respect to the estimated baseline during the 2014-2024 period. However, this reduction will be accompanied by an expected 3.4% increase in

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the marginal cost of power production on the main Chilean power system. In contrast, the introduction of some energy efficiency measures, aimed to reduce 2% of the power demand of the residential sector, could achieve larger reductions in CO_2 emissions, while simultaneously decreasing energy price.

Key words: Energy Efficiency, Carbon tax, Greenhouse gas emissions, Climate change policy

JEL Classification: C81- D04- D61-H30

1. Introduction

Nowadays it is impossible to imagine our daily activities without the use of energy in its many forms. Likewise, it is not possible to imagine the development of economic activities of countries without the use of energy. There is a consensus that having energy for economic growth and development of countries is necessary. A country with a larger availability of energy will have a higher potential growth to be achieved. In the same way, if countries can produce and use cleaner energy, the world economic development will be more sustainable [1-7]. One of the negative byproducts of producing energy is the global air pollution (i.e., emissions of greenhouse gases, GHG [8-17]).

To reduce GHG emissions, countries have proposed a variety of measures [4,5,9,11-14,18,19,20,21,22]. Some of them aim to the promotion of power generation through renewable energy sources. Renewable generation allows not only reducing CO_2 emissions and helping to decrease climate change problem, but also allows decreasing the dependence on fossil fuels. This is particularly relevant for countries that are net importers of fossil fuels, like Chile [4, 5, 9, 19,20,23,24,25].

In this sense, reducing the use of fossil fuels to generate energy is an important issue to resolve, particularly considering their current large consumption worldwide in the power sector. Accordingly, the power sector has become one of the major producers of GHG worldwide [4, 10,11,13,24,26].

Other mechanism that countries have been using in order to reduce their GHG emissions is to fix emission standards. This is a command-and-control scheme where maximum levels of particulates or gases emissions are allowed. This scheme encourages the incorporation of particulate and CO_2 emissions capture technologies. In the same vein, tax-based policies have been implemented in some countries. All these measures are defined under the principle that the polluter should pay for the negative externalities that are produced (polluters-pay principle). This payment can be done either through a fine when the maximum level allowed is surpassed or with a carbon tax over the CO_2 emissions [14, 27-33].

In this context, some environmental policies have directed their actions towards carbon taxes, in order to reduce GHG emissions. However, there are still some aspects of the planning and implementation of these taxes where there are disagreements. This is especially true regarding their effectiveness and the negative effects they can have over the economic development of the countries. Some authors have argued that a carbon tax is regressive because it produces an increase in energy prices affecting the least privileged people in society; while other authors go further and conclude that a carbon tax affects negatively the economy of the countries through its less competitiveness in global markets caused by the resulting higher energy prices [34, 35-43]. In contrast to this line of analysis and conclusions, there are other authors indicating that a carbon tax is an efficient method to reduce the energy intensity of a country and to decrease the demand for energy, which in turn produce a decrease in GHG emissions. The rationale followed by these authors is that a carbon tax encourages improvement in technologies, equipment and capital investments in the countries where it is implemented [14, 26, 44, 45].

In a different line of action, but also with the aim of reducing CO_2 emissions, there are mechanisms seeking to make a more efficient use of energy. That is, they optimize the energy use without decreasing production of goods or services generated. This concept is named energy efficiency (EE). Some EE measures are the labeling of appliances and cars, the replacement of bulbs and modification of lighting systems, the design and implementation of more efficient technologies, the definition of standards for equipment and machinery, and programs of education and diffusion which promote cultural changes in the people, necessary aspect to improve the efficient use of energy [3, 6, 16, 46].

Among the benefits associated with EE, and that have encouraged their implementation in several countries, can be mentioned its contribution to the reduction of GHG emissions, and therefore decreasing climate change problem, the local improvement of the environment because of the reduction of particulate emissions, the decrease of the electrical energy consumption and the demand picks and, therefore, the delay of the investment requirements for power generation, among others [3,4,6,21,46-55].

Thus, we can recognize the existence of different kind of mechanisms that have been defined by countries in order to achieve their proposed goals about reducing GHG emissions. These mechanisms can be used in isolation or in a coordinated manner, so as to enhance and improve the results achieved. However, it should be noted that each of these measures has its own design characteristics, implementation and possible side effects in markets where they may be applied. All these factors should be taken into account when energy and environmental policies and strategies are defined in order to reduce CO_2 emissions. Also, the particular conditions of the territory and its economics issues should be considered where these policies and strategies are projected, so as to enhance the desired results without affecting other critical variables related to the generation and use of energy and its implications in the different markets. Accordingly, these characteristics and constraints should be taken into account in the design process of energy and environmental policies and strategies, because they can affect results achieved including undesired aspects that can be produced by measures defined. In this sense, a measure designed to reduce emissions of greenhouse gases, could not only produce the desired GHG reduction, but it can also produce other adverse effects, such energy price increase, affecting the economic performance and competitiveness of the country.

In this paper, we compare the effectiveness of reducing CO_2 emissions of the carbon tax recently imposed by the Chilean Government (\$5/ton of CO_2) and of some energy efficiency measures in the residential sector. In particular, we compare the reduction in the CO_2 emissions during a 10-years horizon of the imposed carbon tax and of implementing EE measures that annually reduce residential-sector power demand between 2% and 5%, in the context of the main Chilean grid.

The objective of this work is to analyze the implications of implementing a carbon tax and of considering EE measures to be implemented in the central interconnected system, main Chilean power system of Chile. In this way, this work contributes to the debate regarding the design of energy and environmental policies and strategies that can be implemented.

The rest of the paper is structured as follows. In section 2, we present some characteristics of the Chilean power system and the model used to obtain the simulation results. Section 3 provides simulation results and their analyses. Finally, Section 4 concludes on the main aspects of the work done.

2. The model

2.1. Background information about the Chilean power system

The Chilean electric system is composed of 4 subsystems. The two largest systems are the Central Interconnected System (SIC) and the Northern Interconnected System (SING), which covered 99.5% of the total country electric generation in 2013. The SIC is the main system of the country. In 2013, the SIC reached 74.3% of the total country electric generation, while the SING reached 25.2% [56]. The Chilean electric system has been developed in the last years with a marked trend in the use of fossil fuels as a source of primary energy. The low cost of coal has been the main driver for the total dependency of Chile from exporting fossil fuels and the carbonization of the Chilean electric system [57]. In the case of the SIC, 2013 generation was composed of 38% hydropower (due to droughts in recent years) and 53% thermal generation (mainly coal and natural gas). The remaining 9% of energy was produced by renewable sources, mainly wind and solar [56]. Coal power generation is cheap, but presents negative externalities associated to global and local pollutant emissions [58]. Additionally, Chile has recognized its vulnerability to climate change due to its main productive activities [59].

Notwithstanding the above, Chile is not a major emitter of GHGs in the global context. Considering only CO_2 emissions from combustion of hydrocarbons, Chilean emissions are about 0.2% of the world emissions, ranking at 61st in the world ranking of per-capita-CO_2 emissions in 2008, with a value of 4.35 t CO_2/capita [59-61]. Chile's share of global emissions has remained constant during the last years, but the country's total emissions have increased significantly, mainly due to their growth in the energy sector [59, 61].

Regarding energy prices, in Chile, prices for large consumers (with a level of consumption over 2,000 kW) are determined by bilateral agreements between parts. In the case of energy supply to end-users whose connected power is less than or equal to 2,000 kW, the price is established by regulation. Customers that make up this market segment are called regulated customers. In this case, the Chilean electricity law distinguishes prices at generation, transmission, and distribution levels. At the generation level, the price is regulated based on "regulated nodal prices", which are set by the Chilean National Energy Commission (CNE) twice a year, in the months of April and October of each year. Nodal prices have two components: the first, called basic price of energy, corresponds to the average in the time of the marginal costs of energy from the power system, operating at the minimum total cost; and the second, called the basic price of peak power, corresponds to the annual marginal cost of increasing the installed capacity of the electrical system, considering the cheapest generating units to provide additional power during the power-system's peak demand hours of the year, increased by a percentage equal to the theoretical power reserve margin of the system [6]. It is worth to mention that, in the last ten years, marginal costs and end-users' energy prices have considerably increased due to the lack of new generation and transmission projects, among other variables [56]. Indeed, in the last four years, the residential customers have seen an increment on their electricity bill by 20%.

Within this context, the Chilean government has passed a new regulation that implements a carbon tax of 5\$/tonCO_2, in the framework of a larger tax reform. Accordingly, we measure the main impacts of the proposed carbon tax in the SIC (main Chilean grid), for the period 2014 – 2024, and compare the optimal power generation matrix, the system average annual marginal cost, and the level of CO_2 emissions, in the presence and in the absence of this carbon tax. The carbon tax approved by the government will take place starting 2017. However, for simplicity reasons, we here analyze the implications of such a carbon tax starting immediately. We simulate the operation of the SIC using the OSE2000 software, which is the software employed by the CNE to set regulated nodal prices. In the next section, we briefly describe this software.

2.2. Mathematical modeling through OSE2000

The OSE2000 model simulates the main Chilean hydrothermal power system (SIC) and its operation. This model determines the optimal dispatch of different electric power plants that belong to this electrical system, through an optimization process of inter-temporal operation of existing water reservoirs in the system. The objective function corresponds to minimize the expected sum of the operation, maintenance and failure costs of the entire system. The mathematical optimization procedure corresponds to a Stochastic Dual Dynamic Program, as detailed below in this section. The model represents the electrical system as a set of multiple nodes, so it considers different constrains about transmission lines and the eventual losses that may occur in these lines. As result of the optimization process, the model provides the optimal economic dispatch of all generating plants in the simulated horizon, along with the power flow through transmission lines and marginal costs at each node of the power system. So, based on these results, it can be possible to determine nodal prices. It is important to point out that, since OSE2000 model includes multiple plants of hydro generation, several feasible hydrologic scenarios are considered in the optimal dispatch problem, as a way to consider the inter-temporal operation of water reservoirs belonging to the analyzed electric system.

The modeling horizon can be defined according to the interest of the analysis. In Chile, this horizon normally corresponds to ten years. Each year is divided in two six-month seasons. The first period runs from October to April of each year and the second one from April to October. In relation to the energy demand, this model considers a projection of residential and industrial demand to the complete period of analysis for each node of the system. Moreover, this demand's projection is divided into three different blocks: high, medium and low demand. The projection of the electric demand is generated by the CNE on the basis of historical data and their expected growth for each node in the following years [62].

The model incorporates as parameters the expansion of both generation and transmission. These parameters are programmed as input to the system (i.e., they are defined exogenously). Each generation plant is classified according to its primary source of energy, so the model works with hydraulic, thermal and renewable power plants. This last case includes solar, wind, biomass and geothermal sources [62]. Finally, each generation power plant has a variable operational cost mainly depending on its fuel cost. Additionally to the above, each plant has a non-fuel variable cost.

The model solved is formulated as a Linear Stochastic Dual Dynamic Program [63]. The objective function corresponds to the minimization of the total expected cost, which includes operational, maintenance and failure costs of the system, in an inter-temporal operation of the water stored in hydrothermal power plants, including its opportunity cost during the period of analysis (which depends on the forecasts of weather in each scenario of hydrology considered in the model). In our case, the horizon is ten years (the 2014-2024 period) and 53 hydrologies are included. OSE2000 is the official model used by the CNE to optimize the operation of the SIC and the SING [63].

The mathematical formulation of the optimization problem is:

$$Z^{*} = min \sum_{t=1}^{N_{DS}} \sum_{s=1}^{N_{sh}} P_{t,s} * (C_{t,s} * X_{t,s} + (1+d)^{t} * f_{T} * (X_{T+1,s}))$$

s.t.

$$A_{t,s} * X_{t,s} + E_{t,s} * X_{t+1,s} = B_{t,s} \;\; \forall \; 1 \leq t \leq N_{DS-1} \, ; 1 \; \leq s \leq N_{sh}$$

$$A_{T,s} * X_{T,s} = B_{T,s} \ \forall\, 1 \leq s \leq N_{sh}$$

$$\check{X}\, min_{t,s} \leq X_{t,s} \leq \hat{X}\ max_{t,s} \ \forall\, 1 \leq t \leq N_{DS-1}\,; 1 \leq s \leq N_{sh}$$

$$\check{X} min_{T,s} \leq X_{T,s} \leq \hat{X}\, max_{T,s} \ \forall\, 1 \leq s \leq N_{sh}$$

Where,

Z^*	: expected cost of system operation
d	: discount rate
t	: subscript of step time
s	: subscript of simulation sequences
N_{sh}	: number of sequences of hydrological simulation
N_{DS}	: number of decision steps in the horizon analyzed

Then, for each stage of decision t and simulation sequence s:

$A_{t,s}$	: matrix of electrical connectivity
$E_{t,s}$	: matrix of hydraulic connectivity
$P_{t,s}$	: probability of sequence s in the stage t
$C_{t,s}$	: vector and penalty costs
$B_{t,s}$	: vector of right side
$X_{t,s}$	: state vector
$\hat{X}max_{t,s}$	: vector of maximum restrictions
$\check{X}min_{t,s}$	: vector of minimal restrictions
$f_T * (X_{T+1,s})$	: future cost function at the border for the simulation sequence s and T stage (last stage of simulation)

Since the number and type of plants, water reservoirs, transmission lines, consumption nodes, hydrologies and steps considered in the simulation are considerable, the problem described above has a large size, which grows exponentially with the number of nodes. Thus, to solve this optimization problem, it is necessary to use some techniques to reduce its complexity. For this purpose, OSE2000 uses a Benders decomposition technique. Also, in order to solve the problem in a reasonable computational time, this system uses two stages. The first one corresponds to an iterative process, of 50 iterations in our case, with the objective to obtain the future value of water, defined as an opportunity cost. This value is incorporated in the second stage in order to optimize the total system cost. More details about the modeling of OSE2000 can be found in [64].

Using the described software, we compare the effectiveness on reducing CO_2 emissions of the carbon tax currently passed in Chile with the effectiveness of some energy efficiency measures in the electrical sector. To assess the impact of introducing a carbon tax in this optimization model, the private costs of thermal power plants were altered, to account for the cost increase produced by the tax. CO_2 emission rates were considered for each thermal power plant according to the type of fuel used for generating electricity. As a way of doing a sensitivity and comparative analysis, we simulate different levels of carbon tax, not only a level of 5$/Ton CO_2 as passed in the recent Chilean tax reform. In the same way, several scenarios of demand response in the residential sector were simulated. Results were compared in terms of the type of power generated, the system marginal cost, and the CO_2 emission reductions. The results obtained are presented in the next section.

3. Simulation Results

3.1. System Baseline

We consider as base case the Business-as-usual (BAU) operation of the SIC, without incorporate carbon taxes or reductions in the levels of the projected demand produced by EE mechanisms. Tables 1 to 3 describe this base case in terms of the power generation (in GWh) of each type of generation source (hydro, coal, natural gas and renewable sources), the average marginal cost of the system for each year and the CO_2 emissions.

Table 1: Base case. Power generation in the SIC by source (GWh)

Case Base Generation Type (Gwh)	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Hydro	28,889	29,831	29,574	31,000	32,825	33,981	34,020	34,013	34,160	36,369	37,251
Coal	13,772	14,141	15,449	15,811	16,349	16,924	19,053	21,172	22,087	21,902	22,550
Natural Gas	4,019	5,692	7,234	7,833	7,801	8,652	9,109	8,949	9,324	9,252	10,387
Oil	2,248	1,037	847	884	866	906	899	872	861	885	947
Renewable	4,384	5,103	5,181	5,251	5,358	5,425	5,538	6,346	7,680	8,513	8,643
	53,313	55,804	58,285	60,779	63,198	65,886	68,619	71,352	74,111	76,920	79,779

Table 2: Base case. Average marginal cost in the SIC ($/MWh)

2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
92.37	70.51	73.33	79.48	77.36	82.30	80.76	79.01	81.89	83.48	91.21

Table 3: Base case. CO_2 Emissions (MtonCO_2)

2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
20.80	20.21	22.10	22.83	23.41	24.49	27.13	29.47	30.67	30.46	31.78

All results obtained under different policy scenarios are compared with the results obtained with this base case (BAU). It is important to point out that the base case corresponds to the actual situation of the central interconnected system, as programmed by the CNE for the next ten years.

3.2. The effect of carbon tax on power generation

To measure the effects that the 5$/Ton$CO_2$ carbon tax would have on the SIC, we first analyze the changes in the power generation matrix produced within the horizon considered. The results obtained are summarized in Table 4. As it can be seen in Table

4, a tax of 5$/Ton$CO_2$ does not produce substantial changes in the conformation of the power generation matrix of the SIC in relation to the base case.

Table 4: Case Tax 5$/Ton$CO_2$. Generation in the SIC by source (GWh)

Case Tax 5$/Ton$CO_2$e Generation Type (Gwh)	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Hydro	28,864	29,957	29,585	31,040	32,874	33,966	34,075	34,123	34,181	36,370	37,322
Coal	13,698	13,923	15,297	15,683	16,240	16,775	18,917	21,096	22,039	21,816	22,477
Natural Gas	4,010	5,711	7,256	7,828	7,786	8,777	9,173	8,878	9,307	9,272	10,331
Oil	2,280	1,036	850	891	854	878	871	862	853	895	965
Renewable	4,470	5,187	5,295	5,347	5,445	5,490	5,591	6,400	7,737	8,573	8,695
	53,321	55,813	58,283	60,789	63,199	65,886	68,627	71,359	74,118	76,926	79,790

In order to perform a sensitivity analysis of this result, the optimal dispatches were determined to each year between 2014 and 2024, considering the introduction of a carbon tax of 10, 15, 20 and 25$/Ton$CO_2$, respectively. The results are summarized in tables 5 to 8. The results obtained in each scenario are not drastically different in relation to the BAU, although some differences arise. To better appreciate the magnitude of these differences, in relation to the base case, figures 1, 2 and 3 show a comparison of the results obtained with the different levels of carbon taxes.

Table 5: Case Tax 10$/Ton$CO_2$. Generation in the SIC by source (GWh)

Case Tax 10$/Ton$CO_2$e Generation Type (Gwh)	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Hydro	28,910	30,002	29,605	31,061	32,937	34,030	34,124	33,940	34,213	36,385	37,259
Coal	13,556	13,766	15,186	15,583	16,033	16,636	18,807	21,013	21,863	21,698	22,375
Natural Gas	4,024	5,713	7,251	7,775	7,819	8,748	9,102	9,013	9,324	9,269	10,407
Oil	2,261	1,027	834	906	863	888	896	869	878	900	973
Renewable	4,573	5,311	5,407	5,459	5,550	5,588	5,696	6,517	7,835	8,673	8,772
	53,324	55,820	58,284	60,785	63,203	65,890	68,625	71,352	74,113	76,925	79,785

Table 6: Case Tax 15$/Ton$CO_2$. Generation in the SIC by source (GWh)

Case Tax 15$/Ton$CO_2$e Generation Type (Gwh)	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Hydro	28,898	29,957	29,651	31,093	32,879	34,001	34,104	34,015	34,215	36,394	37,319
Coal	13,442	13,693	15,055	15,439	16,017	16,564	18,710	20,891	21,841	21,598	22,286
Natural Gas	4,041	5,722	7,246	7,815	7,823	8,775	9,180	9,010	9,295	9,291	10,386
Oil	2,292	1,041	853	914	866	898	880	857	868	908	980
Renewable	4,653	5,406	5,481	5,528	5,620	5,651	5,753	6,580	7,898	8,735	8,815
	53,326	55,819	58,286	60,788	63,206	65,890	68,627	71,354	74,118	76,926	79,785

Table 7: Case Tax 20$/Ton$CO_2$. Generation in the SIC by source (GWh)

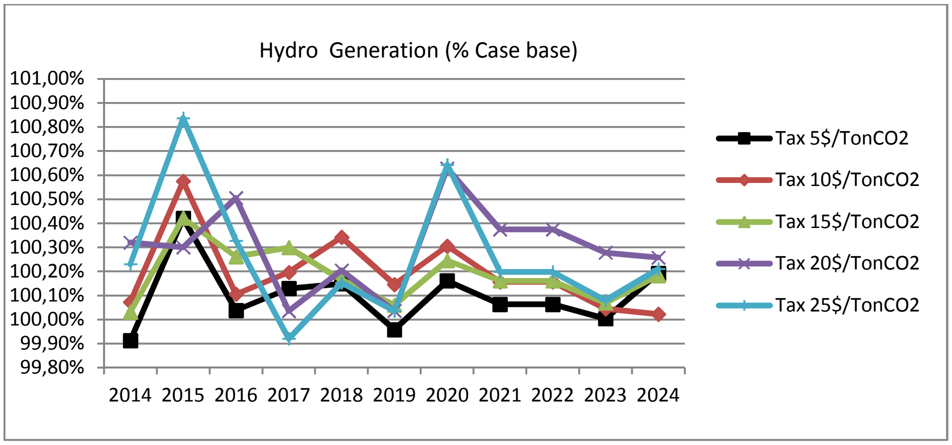
Case Tax 20$/Ton$CO_2$e Generation Type (Gwh)	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Hydro	28,981	29,921	29,723	31,011	32,892	33,993	34,234	34,007	34,288	36,470	37,347
Coal	13,327	13,584	14,833	15,419	15,933	16,517	18,663	20,851	21,737	21,515	22,262
Natural Gas	4,072	5,803	7,359	7,868	7,872	8,835	9,090	9,016	9,300	9,277	10,376
Oil	2,252	1,058	842	898	859	880	863	870	873	903	968
Renewable	4,695	5,450	5,535	5,584	5,659	5,671	5,783	6,614	7,924	8,768	8,839
	53,327	55,816	58,293	60,782	63,214	65,896	68,634	71,357	74,121	76,932	79,791

Table 8: Case Tax 25$/Ton$CO_2$. Generation in SIC by source (GWh)

Case Tax 25$/Ton CO_2e Generation Type (Gwh)	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Hydro	28,955	30,081	29,671	30,975	32,875	34,025	34,239	34,067	34,228	36,397	37,329
Coal	13,260	13,417	14,721	15,364	15,867	16,445	18,549	20,776	21,679	21,487	22,225
Natural Gas	4,072	5,804	7,483	7,941	7,934	8,851	9,167	9,009	9,405	9,361	10,429
Oil	2,294	1,030	843	893	866	880	874	875	869	901	957
Renewable	4,749	5,482	5,572	5,611	5,675	5,692	5,808	6,635	7,944	8,784	8,852
	53,321	55,813	58,283	60,789	63,199	65,886	68,627	71,359	74,118	76,926	79,790

Figure 1 shows the evolution of the hydraulic generation between 2014 and 2024, as a percentage of the generation under the base case, when introducing different levels of carbon taxes. Figures 2, 3 and 4 in turn, show the same analysis, but with the power generation based on coal, natural gas and renewable sources.

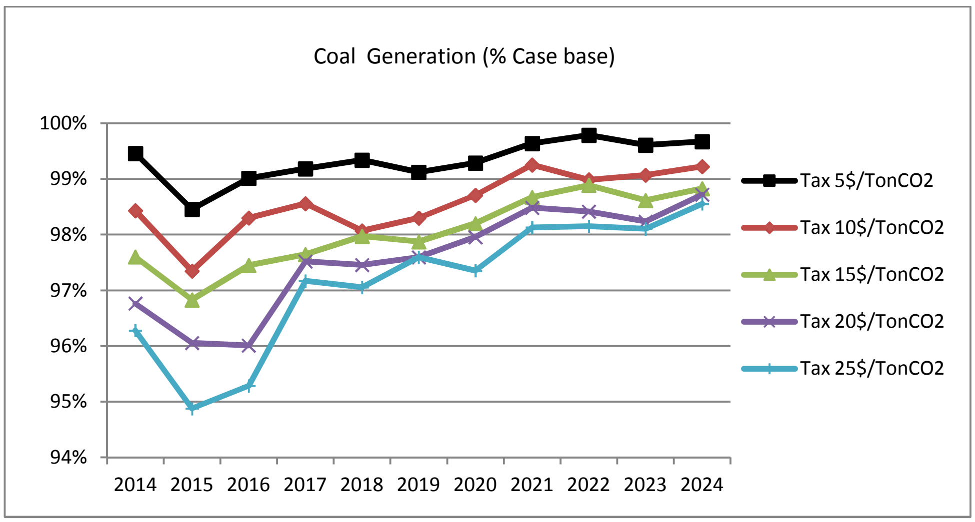
Figure 1: SIC Hydro generation (2014-2024) in different scenarios as a percentage of the generation under the base case



From Figure 1, it is observed that the hydro production increases as the carbon tax is higher, as expected. However it should be noted that the production level depends on the stochasticity of hydrological scenarios. Peak hydro production levels in 2015 and 2020 are explained due to the expected entry of some new hydro generation power plants in the SIC. From Figure 1, we also observe that the increases in hydro production due to higher carbon taxes are not very significant. This can be partially explained due to the lack of large hydro projects to satisfy future power demand.

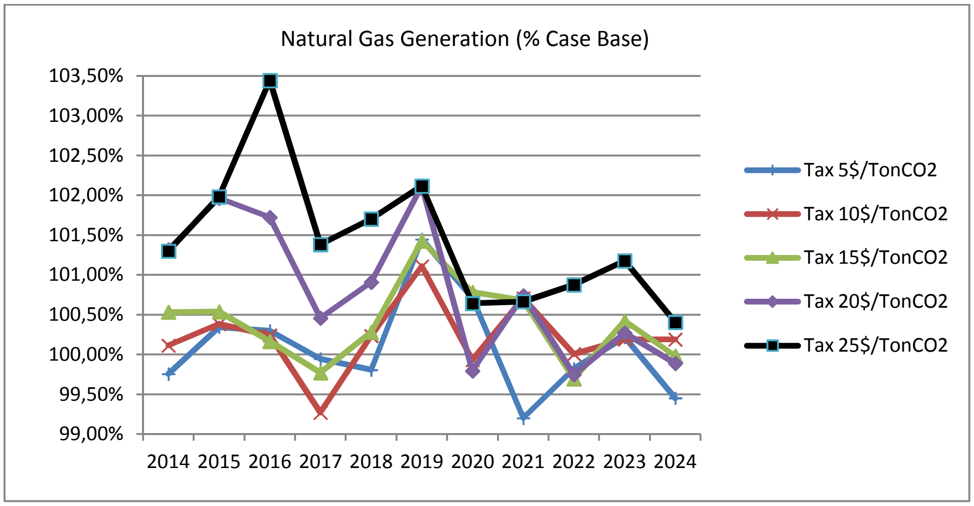
In the case of coal generation, as expected, the introduction of carbon taxes produces a reduction on the power generation. As shown in Figure 2, the higher the carbon tax, the lower the coal generation. However, it is interesting to observe from Figure 2 that the generation reduction due to the carbon tax occurs mainly in the first four years. As the system evolves, this generation reduction gradually decreases and the coal power generation asymptotically returns to the base-case levels. These results suggest that these levels of carbon taxes do not produce a stable change over time in the SIC due to the lack of cheap generation alternatives to coal in the system. Thus, as demand continues growing and hydro and renewable resources are limited, coal production becomes again competitive relatively soon. It is worth to mention that this result obviously depend on our assumption that the generation investment plan does not change as a response to the different levels of carbon taxes, which may not necessarily be the case. In the event that taxes would encourage important investments in renewable energy, for instance, the asymptotic trend observed in Figure 2 would be diminished.

Figure 2: SIC Coal Generation (2014-2024) in different scenarios in relation to case base



A similar asymptotic behavior, but in the opposite direction, is observed in the case of power generation using both natural gas and renewable sources. From Figure 3, we observe that natural gas use increases with the carbon tax in the first four years, but it decreases after that, gradually and asymptotically returning to the base-case levels. Again, this is partially explained because we are assuming there is no additional infrastructure on natural gas built (as it is expected in the CNE's expansion plan). In the case of the renewable energy sources, as observed in Figure 4, this effect is more notorious.

Figure 3: SIC Natural Gas Generation (2014-2024) in different scenarios in relation to case base



As it can be observed from the figures 1 to 3, the economic effects of incorporating a carbon tax are not sustainable over time in the SIC due to the steady increase of demand for energy and the lack of low-cost alternative sources to produce energy. That is, although the carbon tax has an important effect in reducing GHG emissions in the early years, these effects are not sustainable over the time period analyzed.

3.3. The effect of carbon tax on average marginal cost

It is also interesting to analyze the impact of carbon taxes on the marginal cost of power production. Table 9 and Figure 5 show the results obtained when considering the same carbon-tax scenarios as before.

Figure 4: SIC Renewable Generation (2014-2024) in different scenarios in relation to case base

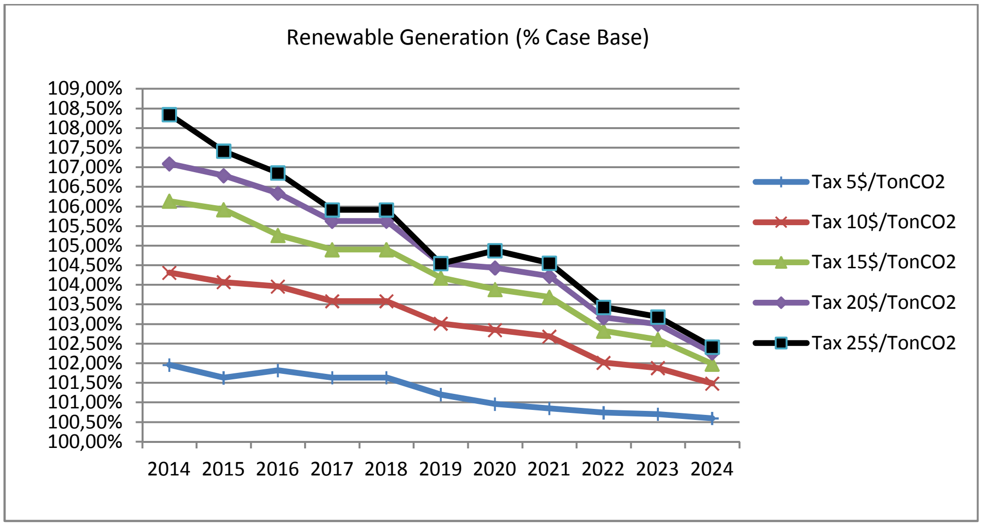
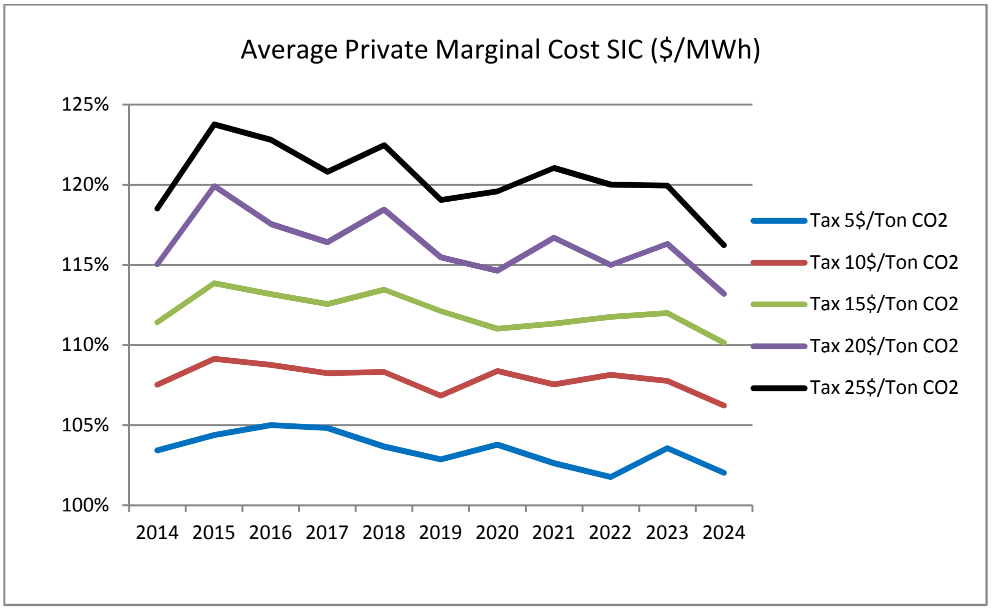


Table 9: Average marginal cost in the SIC under different carbon-tax scenarios (in $/MWh)

Scenario	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Case Base	92.37	70.51	73.33	79.48	77.36	82.30	80.76	79.01	81.89	83.48	91.21
Tax 5$/Ton CO_2e	95.53	73.59	76.99	83.31	80.19	84.64	83.81	81.08	83.33	86.46	93.05
Tax 10$/Ton CO_2e	99.31	76.95	79.75	86.02	83.79	87.92	87.53	84.96	88.56	89.96	96.88
Tax 15$/Ton CO_2e	102.91	80.27	83.00	89.45	87.77	92.27	89.65	87.97	91.52	93.50	100.45
Tax 20$/Ton CO_2e	106.26	84.55	86.20	92.52	91.63	95.03	92.58	92.20	94.17	97.10	103.25
Tax 25$/Ton CO_2e	109.47	87.26	90.06	96.01	94.75	97.98	96.59	95.64	98.29	100.14	106.02

Figure 5: Average marginal cost in the SIC as a fraction of the cost in the base case



As expected, the introduction of carbon taxes produces an increase in the energy marginal cost, which depends on the magnitude of the tax. Considering a tax of 5$/Ton CO_2, as passed by the Chilean government, the system marginal cost would increase by 3.4% in average with respect to the base case. It can be observed from Figure 5 that the system marginal cost does not have the asymptotic behavior of figures 2, 3, and 4. This is because the cost of the carbon tax is not "absorbed" by the system, but just passed through to end customers in the form of a more costly generation production. This more costly generation production represents the cost that is paid for reducing emissions. It is important to remark that we do not valuate the benefits of reducing emissions in this work.

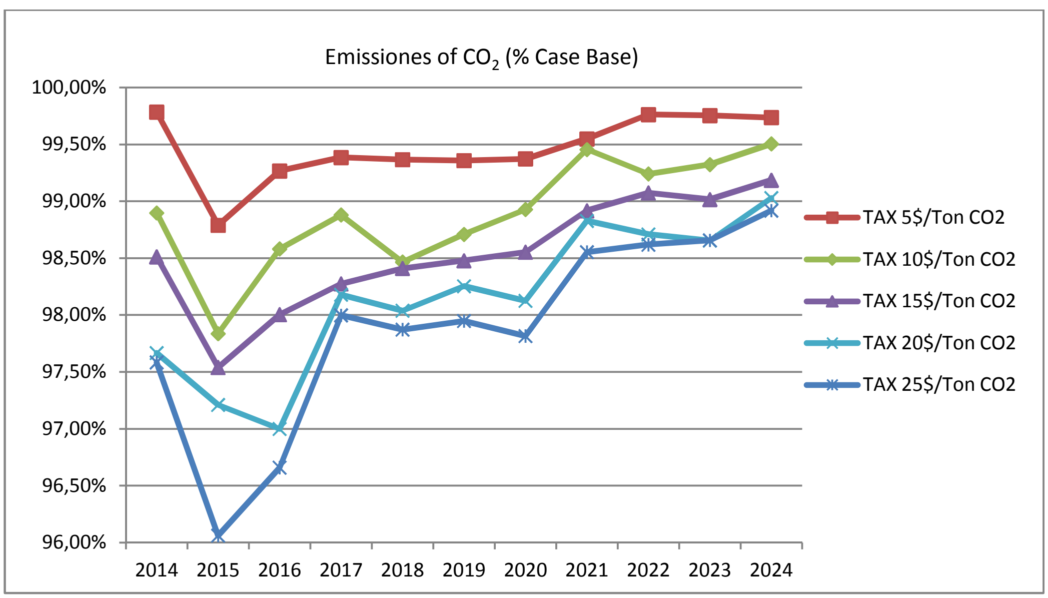
3.4. The effect of carbon tax on CO_2 emissions in the SIC

We now analyzed the reduction of CO_2 emissions produced by the introduction of different levels of carbon taxes. Table 10 and Figure 6 present the results in the carbon-tax scenarios analyzed.

Table 10: Emissions of CO_2 in the SIC in the different scenarios ($MTonCO_2$)

Scenario	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Case Base	20.80	20.21	22.10	22.83	23.41	24.49	27.13	29.47	30.67	30.46	31.78
Tax 5$/Ton CO_2	20.76	19.97	21.94	22.69	23.26	24.34	26.96	29.34	30.59	30.38	31.70
Tax 10$/Ton CO_2	20.57	19.77	21.79	22.58	23.05	24.18	26.84	29.31	30.43	30.25	31.62
Tax 15$/Ton CO_2	20.49	19.71	21.66	22.44	23.04	24.12	26.74	29.15	30.38	30.16	31.52
Tax 20$/Ton CO_2	20.32	19.65	21.44	22.42	22.95	24.07	26.63	29.12	30.27	30.05	31.47
Tax 25$/Ton CO_2	20.30	19.41	21.37	22.37	22.91	23.99	26.54	29.04	30.24	30.05	31.44

Figure 6: Emissions of CO_2 in the SIC in the different scenarios as a fraction of the emissions in the case base



As it can be observed in Figure 6, the carbon tax passed by the Chilean government (5$/Ton CO_2) produce an annual average in CO_2 emissions reduction of less than 1% in the analyzed period. This amount is doubled, in the same period, when the carbon tax reaches 25$/Ton CO_2. The drastic drop in CO_2 emissions in 2015 is mainly explained due to the entry of a large hydro power plant, as mentioned before.

More interestingly, as mentioned before, the effects of the carbon taxes are gradually reduced over time, until nearly reaching the base case levels in 2024. Again, this is mainly explained because demand continues growing and we are assuming that hydro and renewable resources are limited, so the system does not have a different choice to produce energy.

This asymptotic behavior is important from a policy viewpoint because, if the generation expansion plan does not change with the carbon tax (as it is assumed in this work), the effectiveness in reducing CO_2 emissions only lasts some few years, and emissions eventually come back to situations of similar levels as in the base case, but with higher levels of energy prices.

3.5. Analysis of the effects produced by some EE measures

In this section we compare the reduction-of-GHG-emissions effect of introducing a carbon tax with the effects of a reduction in the residential demand due to the implementation of some EE measures. In particular, we analyze the effects that a reduction in the projected residential demand of the Chilean SIC system would have, for the period 2014-2024. This analysis was conducted in two parts. Firstly, a decrease in the projected demand is introduced in the simulations. We evaluate the effects of reducing 2, 3, 4 and 5% of the growth rate of the demand at every node of the network with respect to the base case. And secondly, these reductions were combined with the carbon tax cases, in order to facilitate the comparison of the joint effects produced by the carbon taxes and by the demand reductions. The results obtained are presented below in tables 11 to 13 and figures 7 to 9. They correspond to the power generation matrix for the period 2014-2024 in the SIC, the average marginal costs of the system and the reduced GHG emissions.

Table 11: Generation by source (GWh) without taxes, but with a reduction of 2% in the estimated demand in relation to base case

Generation Type (Gwh)	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Hydro	28,812	29,839	29,541	30,984	32,882	32,882	34,132	33,991	34,173	36,346	37,264
Coal	13,520	13,821	15,209	15,626	16,076	16,076	18,811	20,944	21,849	21,621	22,330
Natural Gas	3,937	5,489	6,899	7,406	7,372	7,372	8,578	8,463	8797	8,768	9,817
Oil	2,092	984	816	857	834	834	852	858	840	870	909
Renewable	4,350	5,047	5,159	5,226	5,328	5,328	5,493	6,310	7,643	8,474	8,602
	52,711	55,179	57,625	60,100	62,492	62,492	67,865	70,566	73,303	76,080	78,922

Table 12: Generation by source (GWh) without taxes, but with a reduction of 3% in the estimated demand in relation to base case

Generation Type (Gwh)	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Hydro	28,829	29,912	29,572	30,968	32,813	33,876	34,077	33,948	34,085	36,296	37,284
Coal	13,371	13,572	15,069	15,495	15,961	16,545	18,668	20,792	21,734	21,466	22,214
Natural Gas	3,903	5,399	6,697	7,223	7,207	8,134	8,431	8,307	8,612	8,583	9,513
Oil	1,981	952	816	863	839	859	835	836	837	860	896
Renewable	4,326	5,028	5,142	5,208	5,318	5,372	5,481	6,292	7,628	8,457	8,582
	52,408	54,862	57,296	59,757	62,138	64,786	67,491	70,175	72,897	75,663	78,489

Table 13: Generation by source (GWh) without taxes, but with a reduction of 5% in the estimated demand in relation to base case

Generation Type (Gwh)	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Hydro	28,706	29,742	29,649	30,999	32,838	34,097	34,124	34,011	34,161	36,312	37,283
Coal	13,163	13,303	14,735	15,254	15,630	16,210	18,406	20,441	21,435	21,166	21,944
Natural Gas	3,795	5,271	6,355	6,824	6,877	7,595	7,924	7,872	8,099	8,095	8,986
Oil	1,853	919	810	838	814	833	830	815	806	836	864
Renewable	4,287	4,991	5,093	5,161	5,270	5,329	5,445	6,256	7,587	8,416	8,553
	51,803	54,226	56,641	59,076	61,429	64,064	66,729	69,396	72,089	74,825	77,630

Figure 7: Coal Generation without taxes, but with a reduction of projected demand in period 2014-2024 in different scenarios

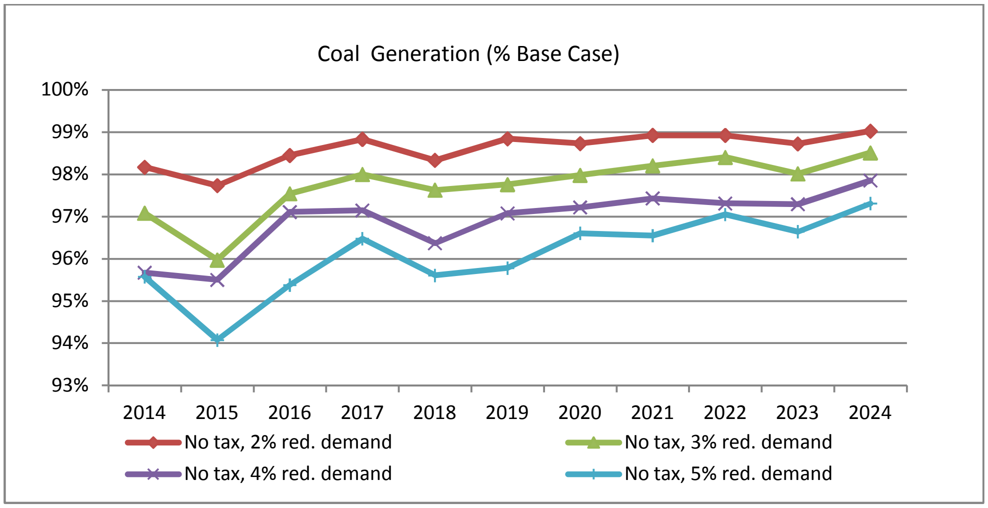
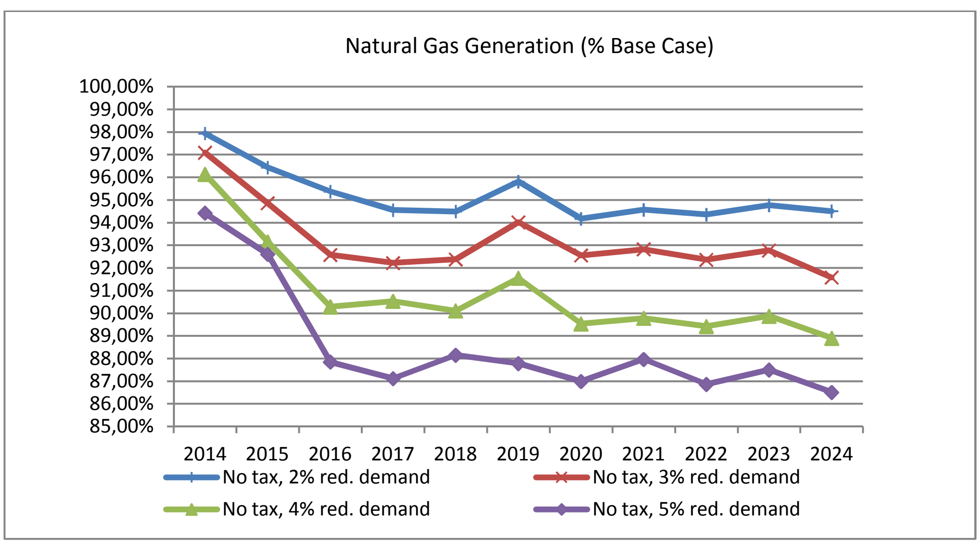
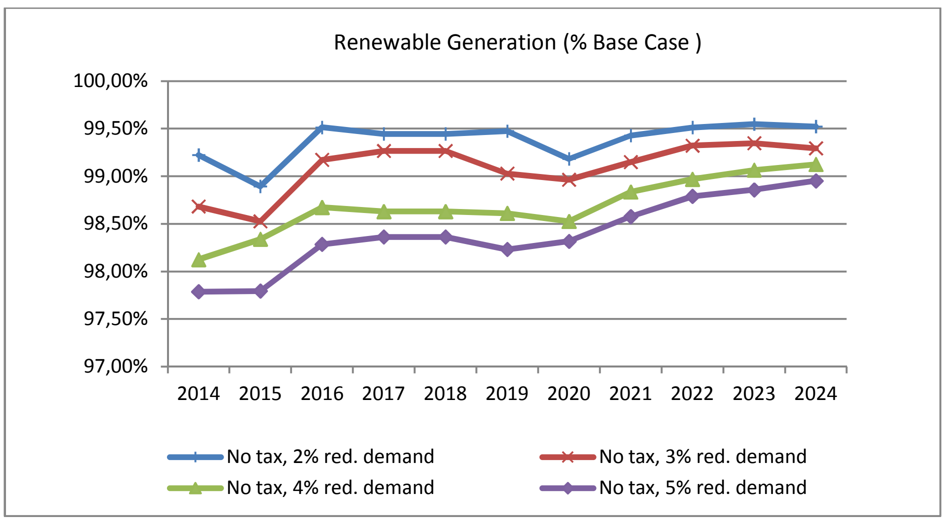


Figure 8: Natural gas generation without taxes, but with a reduction of projected demand in period 2014-2024 in different scenarios



From figures 7 to 9, it is interesting to note that we also observe an asymptotic behavior of the coal power generation, as well as an opposite-direction asymptotic behavior of the natural gas and renewable energy production. However, the asymptotic effect is less severe in these cases than in the cases of introducing carbon taxes mainly due to the fact that the demand reduction put less stress in the system to meet demand. Thus, initial coal generation levels recover over time at a slower rate.

Figure 9: Renewable generation without taxes, but with a reduction of projected demand in period 2014-2024 in different scenarios



A comparison among the marginal cost of the system under different scenarios of demand reductions and carbon taxes is presented in Figure10. In particular, Figure 10 compares the base case with the cases where: (i) a carbon tax of 5$/Ton CO_2 is introduced and there is no demand reduction, (ii), a carbon tax of 5$/Ton CO_2 is introduced and there is a 2% demand reduction and (iii) a carbon tax is not introduced and there is a 2% demand reduction. Figure 10 makes clear that combining a carbon tax of 5$/Ton CO_2 in the system and a reduction of 2% in the residential electrical demand leads to a decrease in the GHG emissions with almost no effect over the system marginal costs in the period 2014-2024. This highlights the potential complementarily between carbon emission policies (such as carbon taxes) and EE policies. Regarding the CO_2 emissions, Figure 11 presents a comparison among different scenarios of the reduction of the CO_2 emissions with respect to the base case. From Figure 11, we observe two interesting results. First, decreasing 2% the projected residential demand is more effective in reducing CO_2 emissions than a carbon tax of 5$/Ton$CO_2$. And secondly, when the 2% decrease in the projected residential demand is combined with the 5$/Ton$CO_2$ carbon tax, a deeper emission reduction is observed. That is, both policies (encouraging EE and carbon tax) are complementary in reducing CO_2 emissions. However, this effect is limited. When a 5$/Ton$CO_2$ tax is introduced and a 2% reduction of the projected demand is jointly considered, the reduction in CO_2 emissions is smaller than when considering only a 3% reduction of the projected demand (with no imposition of any carbon tax). This suggests that promoting EE measures may be a more efficient way to reduce CO_2 emissions than carbon taxes since they are effective in reducing CO_2 emissions and they do not increase the marginal cost of energy production, as carbon taxes do. This conclusion is very important in the case of Chile, where energy prices are among the highest in the Latin-American region.

Naturally, there are several assumptions made in our analysis, like ignoring the increase in the system cost due to the implementation of EE measures. However, several studies have concluded that the EE potential in Chile is still very high, even having several EE measures with negative net costs. Thus, we believe this assumption does not change our general conclusions.

Figure 10: Comparison of average marginal cost among different scenarios in period 2014-2024

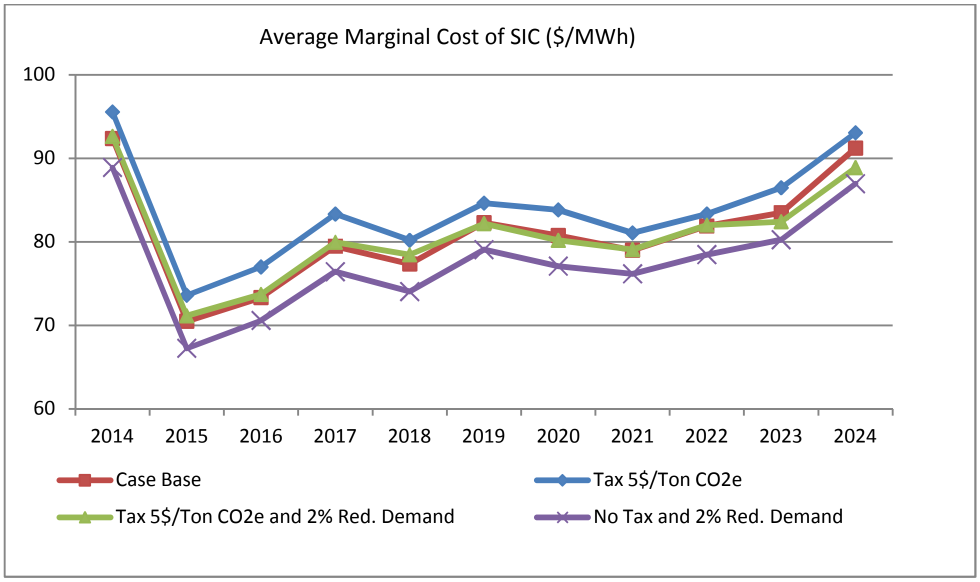
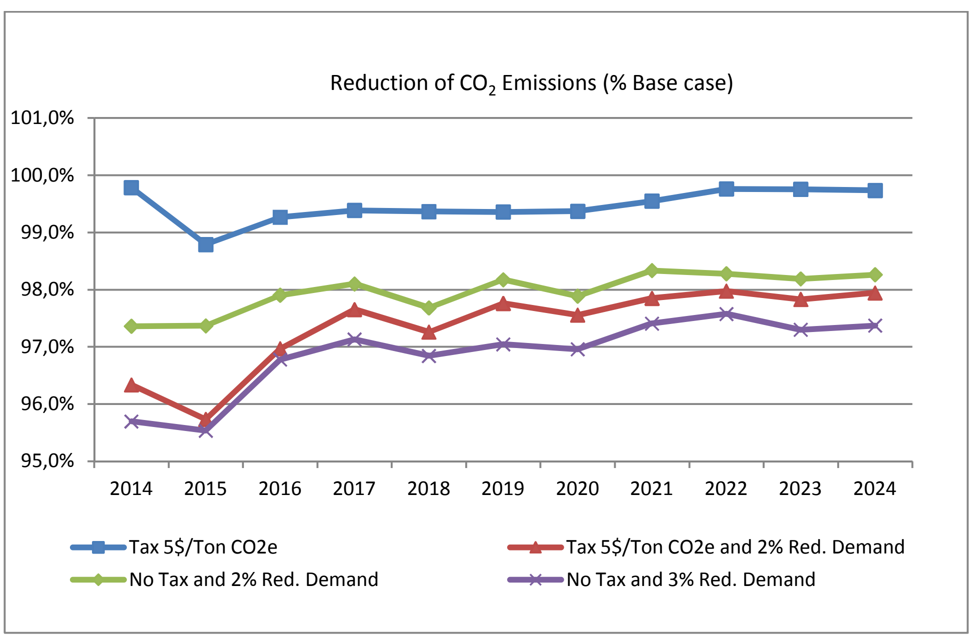


Figure 11: Comparison of the reduction of CO_2 emissions among different scenarios in period 2014-2024



4. Discussion

In this work we have presented a comparison among different measures to reduce CO_2 emissions of the Chilean power system. One of them is based on the recent governmental order of a carbon tax of 5$/Ton CO_2. Simulating the hydro-thermal main Chilean system in a model using stochastic dual dynamic programming, we find that this tax reduces CO_2 emissions in an annual average of 1% with respect to our base case, in the period 2014-2024. The introduction of this carbon tax would also increase the system marginal cost in an average of 3.4%, compared to the base-case levels.

We compare the effectiveness on reducing CO_2 emissions of the carbon taxes with the effectiveness of some energy efficiency measures in the power sector. We show that the introduction of some energy efficiency measures reducing 2% of the power demand in the residential sector could achieve larger reductions in CO_2 emissions than the imposition of the carbon tax, while simultaneously decreasing the price of energy. Moreover, when a 5$/Ton$CO_2$ tax is introduced and a 2% reduction of the projected demand is jointly considered, the reduction in CO_2 emissions is smaller than when considering a 3% reduction of the projected demand (with no imposition of any carbon tax).

The results obtained in this work are important to policy makers because they provide information to support the definition of energy policies and strategies for the country. In Chile, energy prices are among the highest in the Latin-American region and one of the main sources of the country´s incomes corresponds to the cooper production in the mining sector, which is highly energy demanding. Thus, any policy that produces an increase in energy prices may be a drawback to reach the objective of maintaining or improving the competitiveness of the country.

Therefore, to maintain the competitiveness of the country and all its industries, Chile requires that its energy and environmental policies do not further increase the price of energy. On the contrary, the proposed and implemented measures should be defined, on one hand, with the aim to maintain and, if it is possible, reduce the price of energy; and on the other hand, to contribute to decouple economic growth and the country's energy consumption, in order to reduce the current energy intensity.

This paper shows that the aforementioned objectives, together with the reduction of GHG emissions can be achieved through the promotion and incorporation of energy efficiency measures as an alternative to the implementation of a carbon tax policy. As the results suggest, incorporating measures with the objective of reducing, for the coming years, the residential demand projected by 2%, not only reduces CO_2 emissions, but also helps to reduce the marginal cost in the main power system of the country, SIC. Notwithstanding the above, the implementation of the carbon tax might be justified in terms of tax collection, which can help financing energy efficiency programs designed to reduce the demand. In this case a tax of 5 $ / Ton CO_2 and a reduction in residential demand projected by 2% jointly implemented enable both reductions in CO_2 emissions and maintaining the level of energy prices.

5. Conclusions and discussion of public policy

The results that we have obtained in this work suggest that promoting EE measures may be a more efficient way to reduce CO_2 emissions than a carbon tax since they are effective in reducing CO_2 emissions and they do not increase the marginal cost of energy production, as carbon taxes do. This last conclusion is very important in the case of Chile, where energy prices are some of the highest in the Latin-American region. Therefore, considering the characteristics of the Chilean power sector, the projected demand growth for the coming years, the current levels of energy prices, and the growing development and competitiveness of Chile’s economy; our results suggest that the introduction of a carbon tax may not be the best way to reduce CO_2 emissions in Chile at this moment. Our results suggest that introducing EE measures in the residential sector would better achieve this aim, keeping or reducing energy prices.

The work presented in this paper helps to provide information that can be considered in the design of energy and environmental policies and strategies, considering multiple relevant variables, like GHG emissions, energy prices and the diversity of the sources available for generation.

Acknowledgements

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3. CONCLUSIONS AND FINAL REMARKS

The research hypothesis: "Energy efficiency can be encouraged through different mechanisms. These mechanisms can be designed to achieve global and specific results that can be assessed through its direct impacts achieved in the short term, as reducing energy consumption, and also through the indirect impacts, that achieve market transformations and promote sustainable effects in the long-term on the efficient use of energy" has been demonstrated through the work developed in the three lines of action defined.

First, with the methodology designed for Impact Assessment of Energy Efficiency Programs, it is possible to measure the direct and indirect impacts, of measures designed to promote EE. By measuring the direct impacts, the effectiveness of mechanisms implemented in the short-term can be evaluated, through for instance, the KWh saved.

In turn, assessing the indirect impacts, allows, on the one hand, estimating the effectiveness of the program in terms of its ability to transform the energy market in the long term, through three axes: Presence, Valuation and Mobilizing capacity; and on the other hand, identify relevant variables that affect performance of EE programs. This information is very useful for the redesign and improvement of the programs and therefore their effectiveness.

Evaluations of both direct and indirect impacts are important and must be complementary in order to promote EE in the long term and get transformations in the energy market.

In the case of this thesis, the designed methodology was applied to 12 programs implemented between 2011 and 2012 by the ACHEE in Industry and Mining, Transport, Commercial, Public and Residential, Education and Training, and Measurement and Verification sectors. The results of the evaluation lead to the conclusion that progress is possible to obtain higher levels of EE, because the concept itself and the interventions made by the ACHEE have a high valuation and contribute to generate a high mobilizing capacity among participants and beneficiaries of the programs evaluated. However, the greatest weakness and the greatest future challenge are to improve dissemination and training. Thus, these results allow redirect efforts to improve EE in Chile.

Additionally, the evaluation of indirect impacts helped identify some relevant factors to improve EE, among these indirect impacts can be mentioned: the involvement of the companies' leaders that are implementing EE programs and the development of awareness activities throughout the organization before the implementation of EE measures. Detecting these factors would improve the design of EE programs, and their implementation.

Secondly, it has been shown that energy efficiency can be encouraged through different-mechanisms. These-mechanisms can be designed to achieve global and specific results. Thus, one of the mechanisms designed to achieve specific results is a flexible tariff scheme that can be defined for each of the nodes of an electrical system according to their consumption and electricity generation cost. In the case developed in this thesis, the design of a symmetric flexible pricing scheme can transmit price signals to the entire chain of generation and consumption of electrical energy, so that residential consumers make consumption decisions according to the actual cost of the generating power available. Furthermore, the pricing scheme is designed to guarantee a return to DISCOs, reducing the uncertainty when there is high volatility in the cost of the energy. In this manner, the proposed TOU system is, by definition, beneficial for DISCOs and it may lead to a win-win situation among DISCOs and consumers. In particular, this work has estimated that the implementation of this flexible prices scheme in Chile, would allow for DISCOs a total potential benefit of 811.7 millions of dollars for the 3-year study period (2005 to 2007), considering initiatives that promote a 5% savings in real consumption during on-peak hours, obtained by the spread or difference between the proposed and the current systems. Meanwhile, some measures as information or education programs can be considered as general interventions. In this work some of these programs designed and implemented by ACHEE have been evaluated.

Moreover, in relation to finding the best alternative to reduce CO_2 emissions, this work has showed that to achieve this regard it is necessary to consider the specific characteristics of each country or region. Thus, the goal of reducing GHG emissions can be achieved without significantly affecting other relevant variables such as energy prices.

Thus, a measure recently imposed by the Chilean Government is a carbon tax of 5$/Ton CO_2e, which is a mechanism to reach global results. In this regard, this work, simulating the hydro-thermal Chilean system in a model using stochastic dual dynamic programming, has found that this tax reduces CO_2 emissions in an average of 1% with respect to the base case, in the period 2014-2024. The introduction of this carbon tax would also increase the system cost in an average of 3.4%, compared to the base-case levels.

For instance, a measure recently imposed by the Chilean Government is a carbon tax of 5$/Ton CO2e. In this regard, this work, simulating the hydro-thermal Chilean system in a model using stochastic dual dynamic programming, has found that this tax reduces in annual average CO2 emissions in an of 1% with respect to the base case, in the period 2014-2024. However, the introduction of this carbon tax would also increase the system annual cost in an average of 3.4%, compared to the base-case levels.

Moreover, comparing the effectiveness of reducing CO2 emissions through carbon taxes and some energy efficiency measures in the electrical sector, it has been showed that the introduction of some energy efficiency measures, considering reducing 2% of the power demand of the residential sector, could achieve larger reductions in CO2 emissions than the imposition of the proposed carbon tax, while simultaneously non-increasing the price of energy. Furthermore, when a 5$/TonCO2e tax is introduced and a 2% reduction of the projected demand is jointly considered, the reduction in CO_2 emissions is smaller than when considering only a 3% reduction of the projected demand (with no imposition of any carbon tax). So, considering the characteristics of the Chilean power sector, the projected demand growth for the coming years, the current levels of energy prices, and the growing economy and competitiveness of Chile, the results obtained suggest that the introduction of the proposed carbon tax may not be the best way to reduce CO_2

emissions in Chile at this moment. Introducing EE measures in the residential sector would better achieve this aim, keeping or reducing energy prices.

Finally, it is important to state that access to clean energy at the lowest cost possible is essential for the sustainable development of countries. Improving the welfare of people is a great challenge for all governments and societies today. In this work, it has been showed that it is possible to improve our use of energy through the incorporation of measures of energy efficiency. These measures not only help to decrease energy consumption, but also they help to reduce our CO_2 emissions, thereby improving our environment. Moreover, it should be noted that the scope of the work presented here has not included the ways in which the different EE mechanisms should be implemented, and therefore, does not define or analyze public and private institutions necessary to implement such measures. This issue, however, remains as an outstanding challenge in need for further development on future jobs.

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